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Abstract: *Orthophoto image segmentation is vital in geospatial analysis, where precise extraction of spatial features is essential. This study presents a Modified Canny Edge Detection Algorithm tailored for orthophoto imagery. The method replaces the Sobel operator with the Kirsch operator to enhance edge sensitivity and applies morphological closing and skeletonization to improve edge continuity and representation. Performance was evaluated against Traditional Canny and Quadtree Segmentation using Intersection over Union (IoU), Dice Score, and runtime. Experiments on seven orthophoto images showed the Modified Canny method achieved the highest accuracy, with an IoU of 75.81%, Dice Score of 83.96%, and a runtime of 0.2000 seconds. Traditional Canny was faster (0.0463 seconds) but less accurate, while Quadtree performed worst across all metrics. The results indicate that the Modified Canny algorithm offers a robust, accurate, and efficient approach for orthophoto image segmentation, serving as a strong foundation for future geospatial image processing advancements.*

Keywords: Orthophoto segmentation, Modified Canny algorithm, Kirsch operator, edge detection, morphological processing

1. INTRODUCTION

Orthophoto images are aerial photographs that have been geometrically corrected through the process of orthorectification to eliminate distortions caused by terrain relief and sensor orientation [1]. These images preserve true geographic scale and serve as rich sources of spatial information, widely utilized in geospatial analysis, urban planning, environmental monitoring, and precision agriculture [2]. However, to extract meaningful information from orthophoto imagery, appropriate segmentation techniques must be employed to accurately delineate features of interest.

Image segmentation is a fundamental task in computer vision and image processing, involving the partitioning of an image into meaningful regions or objects based on attributes such as intensity, texture, or color [3]. Accurate segmentation serves as a prerequisite for high-level image analysis and decision-making. Nevertheless, the complexity of orthophoto images—stemming from terrain variation, lighting conditions, and image noise—often challenges the effectiveness of conventional segmentation methods [4].

Traditional segmentation techniques, including region-growing [5], thresholding [6], clustering (e.g., k-means) [7], and edge-based methods such as active contours [8], have shown varying degrees of success. However, their performance tends to degrade when applied to high-resolution orthophoto images, primarily due to the intricate details and variability present in such imagery.

The Canny edge detection algorithm, introduced by Canny in 1986, remains one of the most widely used methods for edge detection [9]. While it performs adequately in many general-purpose applications, its sensitivity to noise and limited directional edge detection capability make it less effective for orthophoto segmentation [10], [11]. The strict parameters of the algorithm and its reduced adaptability to complex scenes can result in fragmented or inaccurate edge maps, particularly in images containing high textures or repetitive patterns [12].

In light of these limitations, this study proposes a Modified Canny Edge Detection Algorithm tailored specifically for orthophoto imagery. The proposed method enhances the standard Canny framework by replacing the Sobel operator with the Kirsch operator—capable of detecting edges in eight directions rather than two [13]. Additional improvements include morphological closing to bridge small edge gaps and improve continuity, as well as skeletonization to reduce detected edges to single-pixel width for enhanced representation.

Furthermore, the methodology incorporates preprocessing steps such as image enhancement and denoising, along with parameter optimization, to achieve robust and noise-tolerant segmentation results. The objective of this research is to advance geospatial and remote sensing applications by providing an efficient segmentation technique capable of supporting tasks such as land cover classification, urban growth analysis, and environmental monitoring with improved precision.

2. MATERIALS

2.1 Software

The proposed segmentation system was implemented and executed on a 64-bit Microsoft Windows 11 operating system environment. Image processing, evaluation, and visualization tasks were performed using Python 3.10, with relevant libraries including OpenCV, NumPy, and scikit-image.

2.2 Software

The experiments were conducted on a machine equipped with an Intel(R) Core(TM) i3-7020U CPU @ 2.30GHz, based on a 64-bit architecture, and 16 GB of RAM. While the hardware is modest, it provided a consistent baseline for evaluating the runtime performance of the segmentation algorithms.

2.3 Datasets

The primary datasets used for testing and evaluation were acquired from OpenAerialMap, consisting of high-resolution orthophoto images and geospatial data. These images capture diverse urban and suburban environments, featuring detailed views of structures, road networks, vegetation, and terrain features. The imagery spans multiple years, contributing to variability in conditions and content. To further enrich the dataset, supplementary images were sourced from licensed stock repositories, ensuring broader representation and testing robustness. Image selection was based on quality, geographic diversity, and content relevance to support effective edge detection and segmentation tasks.

3. METHODS

3.1 Concept of the Study

The proposed segmentation system was implemented and executed on a 64-bit Microsoft Windows 11 operating system environment. Image processing, evaluation, and visualization tasks were performed using Python 3.10, with relevant libraries including OpenCV, NumPy, and scikit-image. This research proposes an enhanced image segmentation method that improves traditional Canny edge detection by incorporating the Kirsch operator, adaptive thresholding, and morphological post-processing to segment high-resolution orthophoto images. The process is designed to extract well-defined feature boundaries from complex geospatial imagery.

First, orthophotos are preprocessed through geometric and radiometric corrections to ensure consistency. These images are then converted to grayscale to reduce computational complexity while retaining structural detail. A Gaussian filter is applied to smooth the image and suppress high-frequency noise, improving edge detection robustness.

Edge detection is carried out using the Kirsch operator, which applies eight directional convolution masks. This directional sensitivity allows for more comprehensive edge identification compared to linear detectors like Sobel. Next, non-maximum suppression is applied to refine the edge map by thinning edges and eliminating irrelevant responses.

To improve edge connectivity and minimize fragmentation, adaptive double thresholding is employed to classify edges into strong, weak, and non-edges. Weak edges are retained only if connected to strong ones, enhancing edge consistency across variable contrast regions.

Finally, morphological operations are used to bridge gaps and eliminate noise, followed by skeletonization, which simplifies segmented regions while preserving structural integrity. The result is a set of closed polygonal shapes representing buildings, roads, vegetation, and other land features within the orthophoto.

3.2 Algorithm Development

The proposed method consists of the following steps:

1. Image Loading: Load the orthophoto image into the system.
2. Grayscale Conversion: Convert the RGB image to grayscale.
3. Gaussian Smoothing: Apply a Gaussian blur to reduce noise.
4. Kirsch Kernel Definition: Define eight directional Kirsch convolution kernels.
5. Edge Detection: Convolve the grayscale image with each kernel to compute gradient magnitudes and directions.
6. Gradient Analysis: Calculate the overall gradient magnitude and direction from the Kirsch responses.
7. Non-Maximum Suppression: Thin edges by preserving local maxima in the gradient direction.
8. Adaptive Double Thresholding: Classify edges based on gradient strength into strong, weak, or suppressed.
9. Morphological Operations and Skeletonization: Use dilation and closing to connect edge fragments; skeletonize to simplify shape.
10. Edge Overlay: Superimpose the detected edges on the original image copy.
11. Image Resizing and Display: Resize and present the final segmented output for analysis.

3.3 Evaluation Metrics

3.3.1 Accuracy Assessment

Two primary metrics were used to evaluate segmentation accuracy: Intersection over Union (IoU) and the Dice Coefficient. Ground truth data was manually annotated, delineating regions such as buildings, vegetation, and roads for comparison.

Where:

A is the set of predicted segmented pixels.

B is the set of ground truth pixels.

$|A \cap B|$ is the area of overlap.

$|A \cup B|$ is the total area covered by both prediction and ground truth.

The Dice Coefficient is defined as:

$$\text{Dice} = \frac{2|A \cap B|}{|A| + |B|}$$

Higher values of IoU and Dice indicate greater similarity between predicted and actual segmentations.

3.3.2 Computational Efficiency

Run Time was used to assess the speed of the algorithm. For each test image, the time taken from execution start to completion (excluding display time) was recorded. The average run time across all images was computed to evaluate overall computational efficiency.

3.4 Overall Performance Evaluation

To validate the proposed approach, comparisons were made against the traditional Canny edge detection algorithm and Quadtree-based segmentation. The performance was evaluated using the mean Intersection over Union (IoU), mean Dice Coefficient, and average run time. Higher accuracy metrics, combined with lower run time, demonstrate the effectiveness of the modified Canny approach using the Kirsch operator and morphological refinements.

4. RESULTS AND DISCUSSION

4.1 Workflow Process of Traditional and Proposed Segmentation Methods

This section describes and compares the workflow phases of the current traditional Canny segmentation algorithm with the proposed new segmentation algorithms, i.e., the Modified Canny and Quadtree Segmentation. Both algorithms possess a well-defined pipeline from data preparation to final assessment. By comparing these workflows, this study determines the value and improvement that the suggested methods provide, paving the way for potential future applications in image processing and geospatial data analysis.

4.1.1 Workflow of Traditional Canny Edge Detection

Data Preparation: The target image is loaded using the OpenCV library in Python. Pre-checks ensure the image's sharpness and correct formatting for better analysis.

Image Preprocessing: The image is transformed into grayscale to simplify manipulation and emphasize pixel intensity variations, which are crucial in edge detection.

Edge Detection (Traditional Canny): The classical Canny edge detection process is carried out as follows. First, Noise Reduction is applied by using Gaussian blurring to reduce noise and enhance the edge detection process. Next, in the Gradient Calculation step, the Sobel operator is employed to calculate intensity gradients in both horizontal and vertical directions. Following this, Non-Maximum Suppression is applied to retain the local maxima in the gradient magnitude while suppressing other values, effectively thinning the edges. Finally, in the Double Threshold and Edge Tracking by Hysteresis step, a double thresholding approach is used to detect both strong and weak edges. Edge tracking is then performed to link weak edges to strong edges, forming consistent contours.

Output and Analysis: The edge map is preserved for visual inspection. Quantitative performance metrics such as IoU and Dice Coefficient are computed by evaluating the output against the ground truth segmentation masks. These metrics provide objective bounds of boundary detection accuracy and completeness using the traditional Canny method.

4.1.2 General Workflow of Modified Canny Edge Detection Method (with Morphological-Skeleton Closing Algorithm)

Data Preparation: The target image is imported into a processing environment such as Python using OpenCV. It is checked for clarity, and if necessary, georeferenced for edge-based segmentation.

Image Preprocessing: The image is converted to grayscale to ease processing and highlight intensity variations, which are essential for gradient-based algorithms.

Edge Detection (Modified Canny): The Kirsch operator replaces the Sobel operator in this method to enhance edge detection by detecting intensity gradients in eight directions. First, Noise Reduction is applied by using Gaussian blur to reduce image noise. Next, in the Gradient Calculation (Kirsch) step, directional kernels compute gradients in multiple directions, leading to stronger and more accurate edges. Following this, Non-Maximum Suppression and Hysteresis Thresholding is applied, which thins the edges and fills them based on intensity thresholds. Then, the Morphological-Skeleton Closing Algorithm is employed to maximize edge continuity through morphological and skeletonization techniques. Specifically, Morphological Closing involves dilation followed by erosion, which links adjacent edge segments and fills small gaps in boundaries. Lastly, Skeletonization reduces closed edge structures to a one-pixel representation, preserving the central geometry and eliminating redundancies.

Output and Analysis: The processed edge map is compared to ground truth hand-annotated masks. Performance is evaluated using IoU and Dice Similarity Coefficients, which measure coverage and accuracy. This method tends to offer better continuity and shape preservation, especially for thin structures such as rooftops or road edges.

4.1.3 General Workflow of Quadtree Segmentation Method

Data Preparation: The target image is imported into a processing environment and preprocessed if necessary (e.g., denoising or resizing) to achieve a balanced segmentation granularity.

Segmentation using Quadtree Decomposition: This method follows a top-down approach. First, the image is recursively divided into quadrants. Each block is then evaluated for homogeneity, such as pixel intensity standard deviation or texture. If a block is non-homogeneous, it is further subdivided. The process continues until all blocks meet a predefined homogeneity criterion or a minimum block size is reached.

Output and Analysis: The segmented image is assessed both visually and numerically. IoU and Dice coefficients are calculated against ground-truth masks to quantify segmentation precision. Visual inspection helps determine if the quadtree correctly captured spatial patterns, particularly in complex urban or natural scenes.

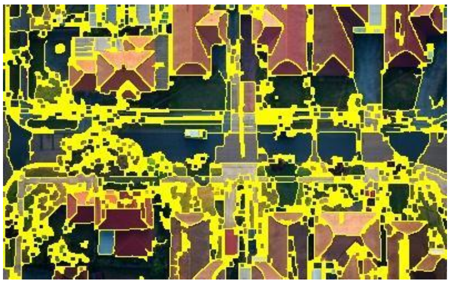
4.2 Results of Kirsch-Based Modifications

This section describes the outcomes of the key modifications made to the segmentation pipeline. The Sobel operator in the traditional Canny algorithm was replaced with the Kirsch operator to enhance directional edge detection. In addition, morphological closing was applied to connect disjointed edges, followed by skeletonization to simplify objects to their core structural form.

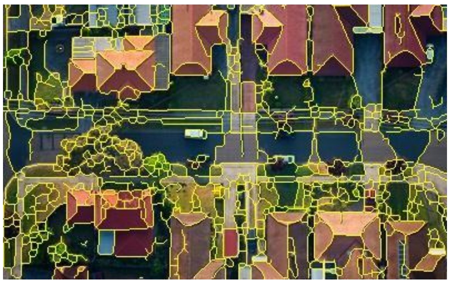
The use of the Kirsch operator improved edge detection, particularly for diagonal and curved features, resulting in stronger and more consistent outlines. Morphological closing significantly improved boundary continuity by filling small gaps between edge segments, thereby enhancing the overall segmentation performance.

Orginal Image

Kirsch-based canny



Morphological closing



Skeletonization (Final Output)

This improvement is clearly shown in Figure 4.2.1, where previously broken contours are visibly connected, especially around building roofs and irregular object edges. Skeletonization then simplified these connected shapes into their core structures without losing form, making the outputs more suitable for downstream tasks like object counting, structure tracing, or shape analysis.

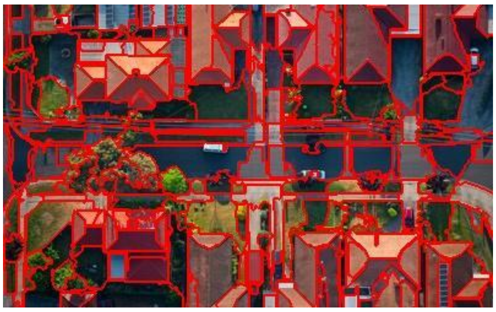
Fig. 4.2.1 Edge Continuity

4.3 Quantitative Metrics and Visual Assessment of Results

This section gives a quantitative and qualitative comparison of segmentation algorithms. Here, the performance of each of the techniques—Traditional Canny, Modified Canny with Morphological Closing, and Quadtree Segmentation—is compared in IoU, Dice Coefficient, and Runtime metrics. These metrics are reliable and unbiased for a comparison of precision, speed, and efficiency of the segmented results against ground truth masks. Comparisons are also shown visually for the edge sharpness, boundary alignment of the objects, and consistency of segmentations for varied samples of images.

Sample 1

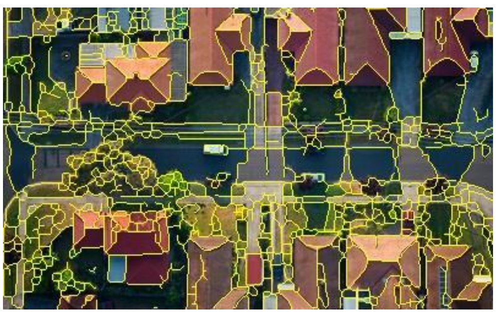
Original Image



Ground Truth

Quadtree

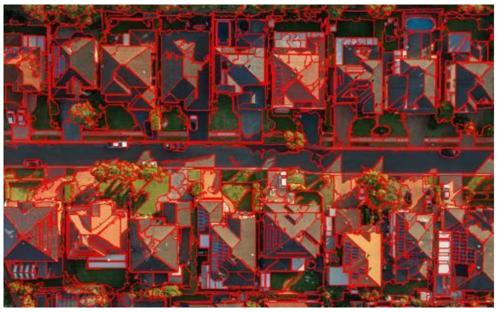
Traditional Canny



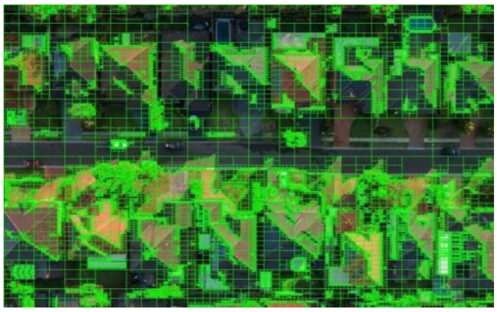
Our Approach

Sample 2

Original Image



Ground Truth



Quadtree

Traditional Canny

Our Approach

This section presents a step-by-step performance evaluation of three segmentation methods: Quadtree Segmentation, Traditional Canny Edge Detection, and Modified Canny Edge Detection. The evaluation was conducted on seven image samples using three primary metrics. First, the Intersection over Union (IoU) was used to measure the accuracy of the overlap between the predicted segmentation and the ground truth mask. Second, the Dice Coefficient was applied to assess the similarity between the predicted segmentation and the ground truth, which is particularly effective for foreground-background segmentation tasks. Lastly, runtime was measured to evaluate the computational efficiency of each method by recording the time required to perform the segmentation process.

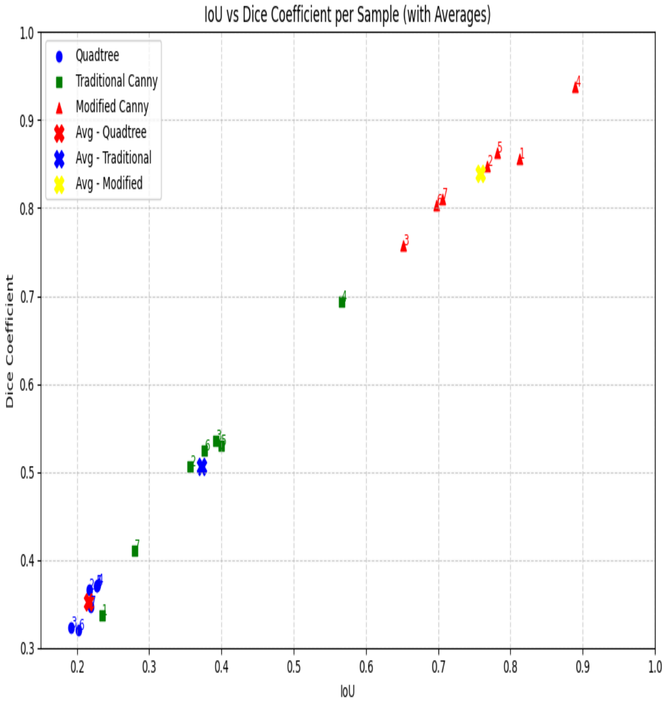


Fig. 4.4.1 Performance Evaluation of Segmentation Methods Based on IoU and Dice Metrics

Fig. 4.4.1 illustrates a scatter plot representing the Intersection over Union (IoU) and Dice Coefficient values for the three segmentation methods—Quadtree Segmentation, Traditional Canny Edge Detection, and Modified Canny Edge Detection—across seven test cases. Each data point corresponds to a specific sample, with distinct markers and colors used to differentiate the methods. The mean values for each segmentation technique are also plotted to indicate overall accuracy and consistency. Higher IoU and Dice scores signify improved segmentation performance, indicating a closer match between the predicted regions and the annotated ground truth. This visualization facilitates comparative analysis by identifying which method achieves more consistent and accurate results across varying image samples.

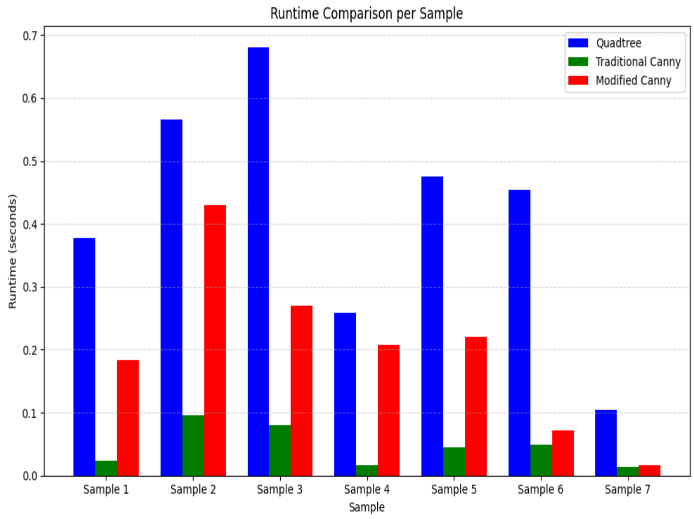


Fig. 4.4.2 Runtime Comparison of Segmentation Methods

The bar chart is used to compare the running time of the three segmentation algorithms—Quadtree, Traditional Canny, and Modified Canny—on all seven samples. There are three bars for each sample, representing the time taken by each algorithm. This allows for a fine-grained examination of performance differences and computational cost on various test cases and provides insight into the efficiency of each algorithm.

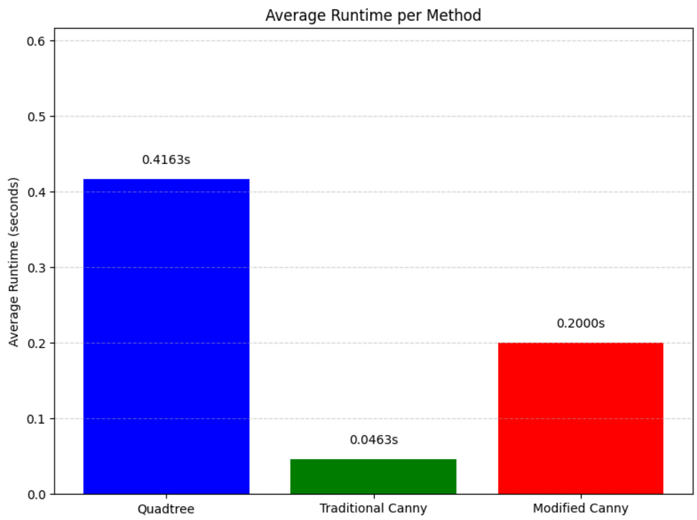


Fig. 4.4.2 Average Runtime per Method

The average runtimes of the Quadtree, Traditional Canny, and Modified Canny algorithms across all image samples are presented in Fig. 4.4.2. This bar chart offers a condensed view of computational performance and serves as a practical measure of algorithmic efficiency. It is instrumental in assessing which segmentation technique sustains competitive processing time without compromising segmentation quality.

Experimental results reveal a significant improvement in segmentation performance with the Modified Canny method over both Traditional Canny and Quadtree-based segmentation approaches. The Modified Canny algorithm achieved the highest Intersection over Union (IoU) and Dice Coefficient scores of 75.81% and 83.96%, respectively. These values indicate that the proposed method exhibited superior accuracy in delineating object boundaries and better agreement with ground truth annotations. The enhancements—namely the substitution of the Sobel operator with the Kirsch operator, followed by morphological closing and skeletonization—contributed to improved edge connectivity and structural precision.

In comparison, the Traditional Canny edge detection algorithm delivered moderate performance, with an IoU of 37.23% and a Dice score of 50.57%. While it outperformed the Quadtree method, it was limited by frequent edge discontinuities, making it less effective for processing high-resolution orthophotos that require detailed boundary representation.

The Quadtree Segmentation technique, though conceptually robust in its hierarchical partitioning, resulted in the lowest accuracy metrics—21.62% IoU and 35.29% Dice score—and the highest average runtime of 0.4163 seconds. Its relatively poor performance may be attributed to the block-based decomposition strategy, which struggles to capture intricate object edges and continuous contours inherent in complex scenes.

Regarding computational efficiency, the Traditional Canny method was the fastest, with an average runtime of 0.0463 seconds. This was followed by the Modified Canny algorithm at 0.2000 seconds and the Quadtree method. Although the proposed method incurs a slightly longer runtime than the traditional approach, the trade-off is justified by the notable increase in segmentation accuracy.

These findings demonstrate that the Modified Canny algorithm achieves a well-balanced compromise between computational speed and segmentation precision. Its performance suggests considerable promise for high-accuracy object detection tasks in orthophoto image analysis.

5. CONCLUSION

This study contrasted the performance of three segmentation algorithms—Quadtree Segmentation, Traditional Canny, and Modified Canny—based on typical benchmarks such as Intersection over Union (IoU), Dice Score, and Runtime, averaged across seven test images.

The Modified Canny method demonstrated the highest accuracy among all the methodologies tested, achieving an IoU of 75.81% and a Dice Score of 83.96%. These results indicate the method's strong ability to align predicted segments with ground truth data. Furthermore, with a runtime of 0.2000 seconds, it offers an optimal balance between computational cost and segmentation accuracy.

In comparison, Traditional Canny, while being the fastest (0.0463 seconds), exhibited only moderate accuracy, making it less suitable for applications requiring high-definition segmentation. The Quadtree Segmentation algorithm performed the worst, with both the lowest accuracy and runtime, highlighting its inefficiency for fine-grained segmentation tasks in complex imagery.

Overall, these findings suggest that the Modified Canny algorithm is the most robust and effective choice for the segmentation of high-resolution orthophoto images. Its strong performance positions it as a valuable tool for future applications in geospatial and remote sensing domains. Further work could focus on optimizing the algorithm's efficiency or integrating it with more advanced image processing frameworks for enhanced performance.

A promising direction for future research is the integration of edge detection with deep learning. Combining traditional methods like the Modified Canny algorithm with Convolutional Neural Networks (CNNs) could enhance segmentation accuracy by refining edge detection and improving performance, especially in complex scenarios like medical imaging or remote sensing. This hybrid approach has the potential to deliver better results than traditional methods alone, offering a valuable avenue for future advancements in segmentation technologies.

6. FUTURE WORK

A promising direction for future research is the integration of edge detection with deep learning. Combining traditional methods like the Modified Canny algorithm with Convolutional Neural Networks (CNNs) could enhance segmentation accuracy by refining edge detection and improving performance, especially in complex scenarios like medical imaging or remote sensing. This hybrid approach has the potential to deliver better results than traditional methods alone, offering a valuable avenue for future advancements in segmentation technologies. Furthermore, integrating these advanced segmentation techniques within Geographic Information Systems (GIS) can significantly enhance spatial analysis capabilities. For instance, GIS-based studies, such as [14][15], utilize spatial data to inform decision-making processes in agriculture . By incorporating refined edge detection and deep learning methodologies into GIS frameworks, researchers can achieve more precise delineation of land features, leading to improved accuracy in applications like crop mapping, urban planning, and environmental monitoring.

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