Road Extraction from RoadNet-based Satellite Imagery Using Classical Computer Vision Techniques
Project Proposal

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Abstract

Road extraction from satellite imagery is essential for urban planning, disaster management, and navigation systems. While deep learning approaches have shown strong results, their reliance on extensive training data and high computational demands motivates the exploration of classical computer vision techniques. This proposal outlines a project to reproduce road extraction using traditional methods on the RoadNet-based dataset. Our goal is to develop a robust, interpretable pipeline that employs image enhancement, edge detection, geometric transforms, and connectivity analysis to delineate road networks accurately. The proposed approach will be evaluated against ground truth annotations using both quantitative metrics and qualitative visual assessment, ensuring reliability and practical applicability.

1. Introduction

Road extraction involves identifying and vectorizing road networks from high-resolution satellite imagery. Accurate extraction is crucial for updating geographic information systems (GIS), planning urban infrastructure, and improving navigation. Given the increasing availability of high-resolution satellite data, there is a growing demand for automated and computationally efficient road extraction methods. However, deep learning-based approaches, while effective, pose challenges related to extensive labeled data requirements, high computational costs, and lack of interpretability.

This project investigates the feasibility of using classical computer vision techniques to extract roads efficiently and robustly. By leveraging edge detection, morphological operations, and geometric transformations, we aim to develop a pipeline that is not only accurate but also interpretable and computationally efficient. This approach is particularly relevant for scenarios where access to high-performance computing resources is limited.

2. Motivation

Our primary motivation for this project is to test and further develop the computer vision skills we have acquired during our course by applying them to a concrete and stimulating real-world problem—road extraction from satellite imagery. This task presents significant challenges, such as handling noise, managing occlusions, and ensuring connectivity in complex urban scenes, which require a deep understanding of image processing techniques.

Given that our course has covered a range of topics—from filtering, feature extraction, stereo vision, and optical flow, to image segmentation and recognition—we are well-prepared to apply these techniques in an integrated pipeline. This project will also allow us to experiment with different preprocessing strategies, tuning methods, and evaluation metrics to refine our approach.

Moreover, road extraction has numerous practical applications, from updating GIS databases to assisting in autonomous navigation systems and disaster management. A lightweight, classical approach could serve as a valuable alternative for organizations with limited computational resources.

Finally, we anticipate that the problem-solving skills honed through this project will be beneficial in diverse professional settings, including healthcare, finance, and industrial automation. If needed, we plan to incorporate advanced techniques from our "*Advanced Topics and Challenge*" sessions to further enhance our pipeline's robustness and adaptability.

3. Problem Definition

3.1 Definition

Given high-resolution satellite images, our objective is to accurately extract and vectorize road networks using classical computer vision techniques. The key challenges we address are:

• **Continuity and Connectivity:** Ensuring that the extracted road network remains continuous and correctly connected, especially in complex urban environments with occlusions or partially visible roads.

• **Noise and Variability:** Managing image noise, variable illumination, and occlusions (e.g., clouds, shadows, or vegetation) that can interfere with feature detection.

• **Edge Discontinuities:** Roads often appear fragmented due to weak edge responses or discontinuities in image data; therefore, our approach must effectively bridge these gaps to maintain road integrity.

• **Parameter Sensitivity:** Classical methods are often highly sensitive to threshold values and filter parameters. To address this, we will explore adaptive techniques that dynamically adjust processing parameters based on image characteristics.

• **Scalability and Efficiency:** The proposed method should be computationally efficient to process large-scale satellite imagery, ensuring practical applicability across various environments.

By addressing these challenges, our goal is to develop a robust and interpretable pipeline capable of extracting roads accurately from diverse satellite imagery datasets.

3.2 Related Work

Recent deep learning methods, particularly the RoadNet model by Chen et al. (2016), have achieved state-of-the-art performance in road extraction. However, these methods require extensive labeled datasets and significant computational resources, which can be a limitation in resource-constrained environments. Classical approaches—such as those by Mena and Gamba (2007) and Mena and Bostrom (2010)—have utilized morphological operations, edge detection, and feature extraction to identify roads, but they often struggle with noise, discontinuities, and parameter sensitivity. Our project seeks to bridge these gaps by integrating adaptive thresholding, curvature analysis, and graph-based connectivity analysis. We will also be open to incorporating advanced techniques, as highlighted in our "*Advanced Topics and Challenge*" sessions, if the initial experiments indicate a need for further refinement.

4. Methodology

Our approach will be structured into the following stages to ensure an effective road extraction pipeline:

• **Preprocessing:** We plan to apply histogram equalization for contrast enhancement, followed by median and bilateral filtering to reduce noise while preserving edges. The image will be converted to both grayscale and HSV color spaces for further analysis.

• **Color-Based Segmentation:** To isolate potential road regions, we will employ a gray-level mask in HSV color space. Morphological closing operations will be used to refine the extracted mask, reducing noise and ensuring continuity.

• **Edge Detection:** We will experiment with different edge detection techniques, starting with the Sobel operator to compute gradient magnitudes. This will be followed by adaptive thresholding and Canny edge detection to robustly identify road boundaries.

• **Morphological Processing:** We intend to apply dilation and closing operations to bridge small gaps in detected edges, enhancing the continuity of extracted roads.

• **Line and Curve Detection:** The Hough Transform will be tested to identify linear road segments. For curved roads, we plan to explore additional contour-based techniques to ensure better representation of road structures.

• **Machine Learning Enhancements:** To improve robustness, we will investigate supervised learning approaches using ground truth annotations. A classifier such as a Random Forest or an SVM could be trained to refine road segment selection based on texture and shape descriptors. Additionally, unsupervised learning methods (e.g., clustering) could assist in further refining extracted road networks.

• **Context-Based Refinement:** If road extraction proves highly challenging due to complex urban environments, we may incorporate building detection as an auxiliary task. Since roads are unlikely to cross buildings, using segmentation techniques to detect houses could help constrain road placements and improve accuracy.

5. Evaluation

To evaluate the effectiveness of our approach, we will use the ground truth annotations provided in the RoadNet-based dataset. Our evaluation strategy will consist of both quantitative and qualitative assessments:

- **Quantitative Evaluation:** We will compare our binary road masks with the ground truth annotations using standard performance metrics such as precision, recall, and F1-score. These metrics will help determine the accuracy of our road extraction pipeline at the pixel level.

- **Qualitative Evaluation:** To ensure that the extracted roads align well with the actual road structures, we will visually inspect the binary masks by overlaying them on the original satellite images. This will help identify potential areas where our approach may need further refinement.

- **Parameter Sensitivity Analysis:** We plan to conduct experiments to understand how variations in thresholds and filter sizes impact the quality of the extracted road network. This analysis will guide us in optimizing the parameter selection to achieve the best trade-off between precision and recall.

Through this evaluation framework, we aim to iteratively refine our approach, ensuring that it effectively captures road networks while minimizing false detections.

References

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