Probabilistic Graphical Models

HW3: Image Analysis and Segmentation for Environmental Mapping

By: Bizuhan Abate ___________GSR/8330/16

Email: bizuhan06@gmail.com

Submitted to: Dr. Beakal Gizachew

Submission Date: May 26,2024

1 Introduction

In this lab assignment, the main goal is to build a pipeline for image analysis using undirected graphical models to map surrounding environmental features surrounding a specified location. This entails a number of related tasks, starting with the retrieval of satellite imagery. Here This involves a series of interconnected tasks, beginning with the retrieval of satellite imagery, which serves as the foundational data source. The next step involves segmenting relevant features and visualizing these features, employing color-coded boundaries to enhance clarity and comprehension. Additionally, integral to our analysis is the determination and printing of the elevation of the specified location, such as a building, thereby enriching our understanding of the topographical context. Here, I have documented every task that I completed to meet the above-mentioned aim.

2 Retrieval of Satellite Imagery Task

To begin, I leveraged satellite imagery APIs to access high-resolution images of the designated location. The satellite imagery was sourced from the Sentinel Hub, a powerful and flexible platform providing access to a variety of satellite data for monitoring and analyzing the Earth's surface. I configured the access parameters, including my instance ID, client ID, and client secret, necessary for interacting with the Sentinel Hub service.

Next, I defined the coordinates of the location I was interested in, which are the latitude 37.7749 (San Francisco) and longitude -122.4194. I also specified a radius to delineate the extent of the area of focus, converting 1000 feet to meters, which is approximately 305 meters. Following this, I created a bounding box encapsulating the center coordinates, aiding in delineating the spatial range for imagery retrieval. With the dimensions and resolution of the desired images established, I formulated a request to the Sentinel Hub API, specifying parameters such as the bounding box, image size, and time interval, along with an evaluation script to process the imagery.

Upon executing the request, I retrieved the satellite image data and saved it to a file for the next task and for further analysis. Subsequently, I loaded and displayed the fetched satellite image, providing a visual representation of the specified location.

3 Retrieval of Elevation Information Task

In this task, I retrieve the elevation information for a specific location using the Open Elevation API. First, I define the coordinates of the location, which are set to the latitude and longitude of San Francisco (latitude: 37.7749, longitude: -122.4194). Then, I create a request URL that includes these coordinates and send an HTTP GET request to the Open Elevation API using the 'requests' library. Once the request is made, I check the response status to ensure it was successful. If the request is successful, I parse the JSON response to extract the elevation data. The elevation at the specified coordinates is then printed, which in this case is 16.0 meters, for further analysis and interpretation.

4 Image Processing and Segmentation Task

In this task, I preprocess the retrieved satellite image and implement an undirected graphical model to analyze and segment the image, identifying relevant environmental features such as forests and grassy areas. First, I load the satellite image and convert it to RGB format. I then resize the image to a consistent resolution of 350x350 pixels, which ensures uniformity in subsequent processing steps. This resized image is displayed for visual verification.

Next, a grid graph is initialized using NetworkX with dimensions matching the size of the preprocessed image (350x350). This graph represents the undirected graphical model. For each pixel in the resized image, a corresponding node is created in the graph, and the color value of each pixel is assigned to the corresponding node as an attribute. Edges are automatically generated in the grid graph to capture spatial relationships between adjacent pixels, representing connections between neighboring nodes in the graph. A potential function is defined to quantify the similarity or dissimilarity between the color values of connected nodes (pixels), with the Euclidean distance between color vectors serving as the potential function.

Messages are initialized between all pairs of neighboring nodes in the graph to facilitate information exchange during the belief propagation process. The belief propagation algorithm is applied iteratively to update the messages between nodes, with messages passed according to the defined potential function and current beliefs. After convergence, beliefs are calculated for each node in the graph, representing the confidence or probability that a node belongs to a certain class (e.g., vegetation). Finally, based on the computed beliefs, the image is segmented into different regions corresponding to environmental features such as vegetation (trees, grass) and non-vegetation areas. The final segmented image is displayed, showcasing the identified environmental features.

5 Visualization of Environmental Features Task

In this task, I visualized the environmental features surrounding a specified location by utilizing an undirected model for edge drawing and color-coded boundaries for region identification. Initially, I identified tree clusters within a segmented image based on pixel values, ensuring precise targeting of relevant nodes. For each tree node, I drew a yellow line from the central location, establishing a visual connection between the specified point and the identified tree clusters.

To further enhance the visualization, I calculated the distance from the center to each tree node and applied distinct color-coded circles based on proximity: blue circles for forests within a 200-foot radius and red circles for forests between 200 and 1000 feet. This systematic approach allowed for clear and accurate depiction of detected regions specially for the ground truth image, ensuring that the boundaries of environmental features such as forested areas were easily interpretable.

6 Evaluation of the Image Analysis and Segmentation Pipeline Task

In this task, the image analysis and segmentation pipeline was assessed for its ability to identify land cover features, such as forested areas and grassy areas, in the vicinity of a specified location. The pipeline was tested on two sets of data: an image generated from Sentinel Hub and a ground truth satellite image Kirkos sub city which is part of Addis Ababa city.

While the segmentation pipeline was able to produce clear visualizations with well-defined clusters and boundaries for the ground truth satellite image of Kirkos sub city, the results for the image from Sentinel Hub were less satisfactory. The image from Sentinel Hub was not clear from the beginning, which led to poor segmentation outcomes, including indistinct boundaries and clusters.

To retrieve elevation information for a specific location for Kirkos sub city using the Open Elevation as I did for the image from Sentinel Hub, I have used latitude 9.005401 and longitude 38.763611, which are geographical coordinates of Addis Ababa, because I couldn't find for Kirkos sub city, and found a precise elevation value of 2355.0 meters.

In contrast, the retrieved image from Sentinel Hub image, which included a location in San Francisco with latitude 37.7749 and longitude -122.4194, showed an elevation of 51.0 meters. This discrepancy in image quality and resulting segmentation accuracy underscores the importance of high-resolution input data for effective segmentation.

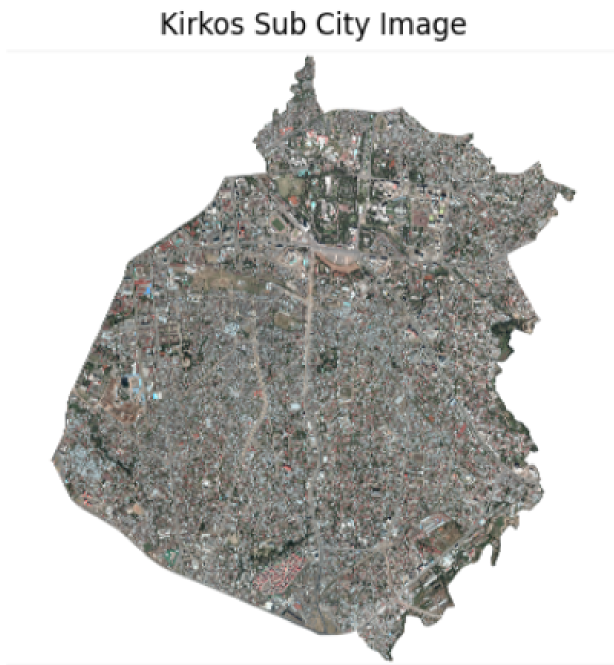
The segmentation pipeline's performance can be significantly impacted by various parameters and functions, such as the number of clusters, initialization methods, and the choice of clustering algorithms. However, the primary limitation in this evaluation stemmed from the initial quality of the Sentinel Hub image. Although fine-tuning the segmentation parameters might improve the results, the clarity and resolution of the input image remain crucial for accurate segmentation.

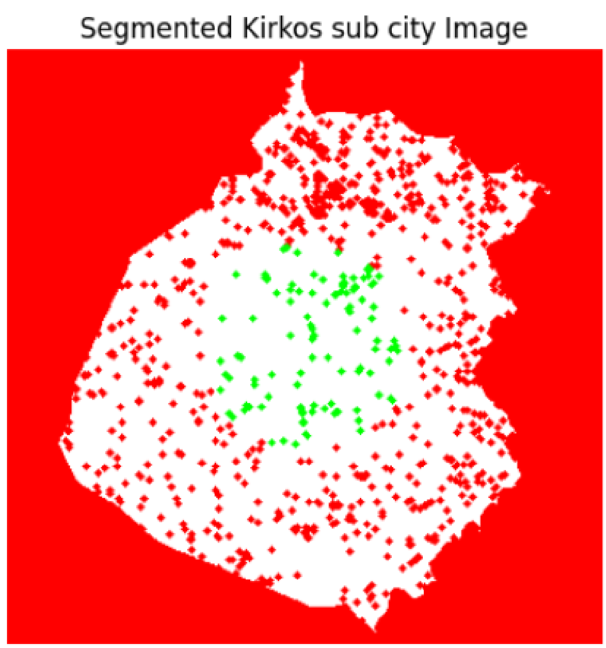
Despite the current limitations observed with the Sentinel Hub generated image, the developed segmentation pipeline has significant potential for environmental mapping and monitoring when high-quality input images are used. Potential applications include forested area identification for assisting in tracking deforestation and forest health and grassy area monitoring for Managing urban green spaces and agricultural lands.

Improvements in image acquisition quality from sources like Sentinel Hub, or employing advanced preprocessing techniques to enhance image clarity, could significantly enhance the pipeline's effectiveness. To clarify the above comparison, Here I have included a fragment of the ground truth as well as the fetched satellite image with their segmented one.

Fetched San Francisco Satellite Image

Segmented San Francisco Satellite Image


Kirkos Sub City Image


Segmented Kirkos sub city Image