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CS412 - IMAGE SEGMENTATION

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1 Introduction

An image is worth a thousand words. Therefore, understanding an image gains a lot of knowledge for human to interact with the world. However, due to the rising number of technologies and accessibilities, there are tons of images out there that human themselves cannot process manually. Therefore, computer vision comes to the rescue as a computing power to understand "thousands of words". Formally, computer vision analyses images and produce relevant contents for human. In particular, image segmentation clusters pixels into "groups" that help other analysis such as object classification or context detection easier. Therefore, this project hopes to demonstrate our team's understanding and implementation of image segmentation.

2 Project Details

2.1 Theory

Image segmentation is intended to "segent" an image into areas (groups of pixels that belong to a cluster). One of the most simple problem is to segment a satellite image (or a high-ground image) into areas with different terrain (or distinct geological terrestrial areas). The authors would like to implement a computer vision application that based on image segmentation that analyses high-ground images and find out what kind of terrains in that image.

2.2 Methodology

There are a variety of methods to do this: cluster based, Intelligent Scissor, etc. to solve segmentation problem. However, due to complexity and different outputs of different methods, methodology is currently in debate to find the best way to represent this problem. However, besides this, the methodology must be able to segment and detect different terrain, and analyze how changes from one terrain to another [1]. In order to satisfy the requirement, we would like to focus on clustering method which is one of the most efficient methods for the implementation of image segmentation. There are different types of clustering: K-mean clustering, subtractive clustering method and Fuzzy C-means clustering method. Among these methods, K-means clustering method is mentioned to be one of the most used algorithms for the implementation [3].

1. K-means Clustering

   - Step 1: Convert original image to grayscale image.
   - Step 2: Use Contrast Stretching to apply high contrast to the image so that it is easier cluster.

     Let P be the intensity of a pixel of the image. Let a be the lower bound and b be the upper bound of the normalized intensity range. Let c is the 5^{th} percentile and d be 95^{th} percentile of intensities range of the image. Then, each pixel is updated by the following formula:

     $$P_{\text{new}} = (P_{\text{old}} - c)\left(\frac{b-a}{d-c}\right) + a$$

   - Step 3: Choose k random cluster potential points or use a heuristic algorithm to predict better cluster points.
   - Step 4: Apply K-means clustering algorithm.

     K-means algorithm uses square of absolute difference:

     $$Distance(A, B) = ||I(A) - I(B)||^2$$

For each pixel, find the closest cluster with above distance algorithm.

- Step 5: Apply median filter to reduce unwanted regions or noise. With a filter size n, choose the medium of intensity within the square size n and replace the middle value weight to be the medium.
- Step 6: Draw colored pixels at the edge of each cluster. (pixels which have neighbor do not belong to the cluster.) (within 3×3 square)
- Step 7: Label deduced clusters.

2. K-means Clustering Optimal Approach
    - Step 1: Convert original image to HSV color image.
    - Step 2: Use Elbow method to select the optimal number K in K-means clustering.
    - Step 3: Apply K-means Plus Plus clustering algorithm.
    - Step 4: Apply median filter to reduce unwanted regions or noise. With a filter size n, choose the medium of intensity within the square size n and replace the middle value weight to be the medium.
    - Step 5: Draw colored pixels at the edge of each cluster. (pixels which have neighbor do not belong to the cluster.) (within 3×3 square)
    - Step 6: Label deduced clusters.

Our first approach is to apply K-means clustering algorithms in combination with image processing methods for grayscale image. The problem is that during the investigating process, we have to face with the clustering problem between grayscale and color image. There is information that only available from color images.

Take the two colors [255 0 255] and [0 179 0] as an example [5].

It can be considered that the two color have the same value when converting to grayscale (105 in Uint8 scale), but we can see visually that they are completely different. With clustering based on intensity of grayscale image containing these two colors, we cannot distinguish the boundary between them, however that problem can be solved with color image.

We decide to use color image instead in order to increase the precision rate. Dealing with color, we have to solve the issue of which color space we should choose with respect to color image segmentation. Actually, there are different methodologies for the image segmentation process, among of them, HSV and L*A*B are usually considered as the good approach in dealing with color image segmentation as its capability to emphasize the visual perception of an image pixel [7] [8]. In [6], a comparative analysis is performed between these two color spaces, the paper also mentions some of related papers about image segmentation that uses these two color spaces and explains the reason as well as the method they use. At the end of the analysis, it is mentioned that HSV color space gives a better result in performance than L*A*B. It is also the reason we decide to use HSV instead.

In term of K-means clustering, it is considered to be one of the most simple and efficient algorithms in segmentation. However, one of the common problems developers usually have to face with is that this procedure require the prior knowledge of segmented data in order to choose the appropriate value of K. Since the result of segmentation depends on the selection of K, we decide to apply Elbow method, the oldest approach for determining the appropriate value of number of clusters in a given data set [9]. According to the method's procedure, it is started with the value of K=2 and keep increasing by 1 until the value of a K sample that we define from the beginning. For each step, calculating the clusters and the cost which is the sum of squared errors (SSE) of the with respect to the data training set. If the value of K-sample is large is enough, at some value of K, the cost drops significantly and reach a plateau in the next steps. That K is the appropriate value for the data set [10].

When applying Elbow method, we have to make sure the value of K-sample large enough in order to find the appropriate K as well as guarantee the performance of the whole process. Since our main objective is terrain images, we decide to select K-sample to be 20.

Until now, we have the value of K, it is time for clustering part. As we mentioned earlier in this section, K-means is one of the most popular algorithms for clustering data.

Given n data vectors $Y_1, ..., Y_{\mathrm{n}} \in R^d$. We choose K vectors cluster centers $c_1, ...c_k \in R^d$ in order to satisfy the equation:

$$R(c_1, ..., c_k) = \frac{1}{n} \sum_{i=1}^{n} \min_{i \leq j \leq k} \left\| Y_i - c_j \right\|^2$$

In fact, the problem of finding $c_1, \ldots, c_k$ in the equation is actually NP-hard. One of the common methods of dealing with it is to randomly pick starting values. This method, however, does not guarantee of getting close to the minimum. Therefore, we have to find a new approach in dealing with this.

Fortunately, in [4], David Arthur and Sergei Vassilvitskii provided us a new method named k-mean++ as a solution for this problem. The algorithm comes with a guarantee of finding the solution in $O(\log k) - competitive$ with the optimal clustering.

1. Take one center c_1, chosen uniformly at random from the data set.
2. Take a new center c_i, choosing x in data set with probability $\frac{D(x)^2}{\sum D(x)^2}$
3. Repeat Step 2. until we have taken k centers altogether.
4. Continue with the standard k-means algorithm.

This method is also provided in OpenCV library as an option of finding center points of k-means method.

After segmentation process is done, it can be seen that the segmented image may still contains some unnecessary regions or noise. So as to improve the quality of the image, we apply median filter which is a nonlinear method used to remove noise from images. There can be a variety of ways to choose the size of filter, the larger value of filter size produces more serve smoothing. According to [3] and [11], it is recommended to choose the filter size to be 7. However, since our data source is from satellite, which contains high quality images, we decide to use the size to be 3.

2.3 Data, Scenarios, and Models

In this project, we use a collection of about 100 images for testing. The data source is available from Google Earth application developed by Google. It provides high resolution terrain images from Google and Satellite Maps as well as geographic data over the Internet. Besides, we want to collect data source from different websites like USGS Earth Explorer, ESAs Sentinel Mission or NASA Reverb. These websites from agencies provide high quality satellite imagery without charge [2]. Our objective is to classify different kinds of terrain based on their colors.

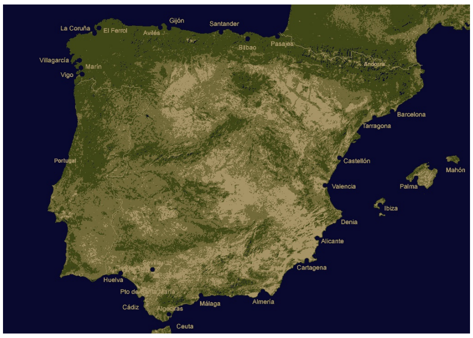
2.4 Time plan for project

In the first two weeks, we decide to gather all necessary data and focus on investigating the methodology of image segmentation. Next, we will try to modify the existing source code based on the proposed algorithm. Beside the algorithm, we will also try to improve the method (using superpixel instead of individual one) and observe the difference. For the final weeks, we will focus on testing and evaluating the application by comparing the results with the sample ones.

2.5 Result

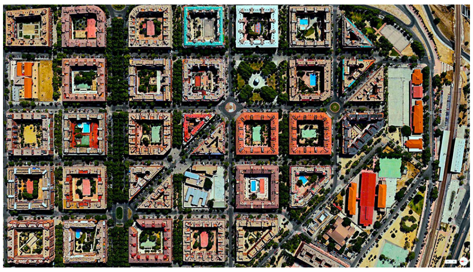
Since our techniques only involve color space segmentation, our system does not reach the level of recognizing objects. However, collecting satellite images can be challenging because there are a variety of objects to identify and learn. What is worse is that, these objects do not contain enough information because they are captured only from above. For example, the roofs in Figure. 2 shows that each house is represented differently though they might be squares. How about rounded houses? They are also houses. How about triangular houses? They are also houses. We may predict that houses and civilization area are in polynomial shapes (or rounded). However, fences or weird structures may noise our prediction. Therefore, we propose a systematic approach to tackle this problem of image segmentation using colors only that we based on colors. From figure 2, 3, 4, they are "grey" areas segmentation. Why? The reason is that although houses are not easily recognizable, houses are mostly connected by roads. What colors of civilized roads? They are mostly "grey". That explains why most of the houses are segmented within the grey area. This raises a method of detecting civilized area using colors of grey and classify other terrains by extracting not on their shapes but on their color (and their neighbor's color) which converge to apply most of the image.

(a) Original Image

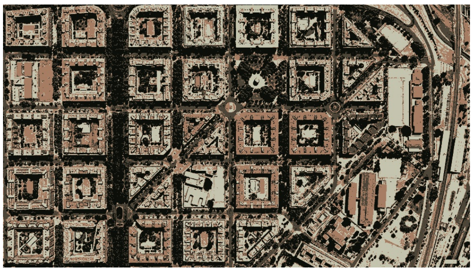


(b) Segmented Image

Figure 1: It gives us the clear view of different kinds of land area.



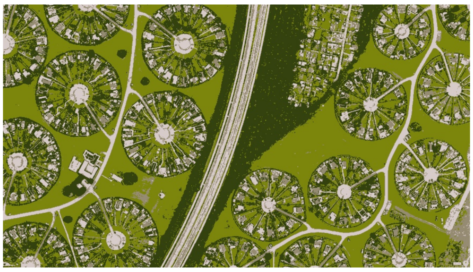
(a) Original Image



(b) Segmented Image

Figure 2: The road is separated from the house area

(a) Original Image



(b) Segmented Image

Figure 3: Houses and road are connected within the grey area

(a) Original Image

(b) Segmented Image

Figure 4: The land area is separated

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