Universidad Carlos III de Madrid

Audio processing, Video processing and Computer vision - Data Science and Engineering

Lab 3.- Image Segmentation

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1. Introduction

In this lab, our objective was to perform image segmentation to identify blood vessels in retinal images. We began with a provided codebase that implemented an initial local threshold approach, which achieved an Intersection over Union score of 0.38. Our primary goal was to improve this baseline performance as much as possible. To achieve this, we applied various techniques and strategies throughout the process.

2. Approaches

2.1. Modifying the codebase (using threshold)

The original code implemented a local thresholding approach that involved using a Gaussian filter to blur the image, followed by the Otsu method to create a threshold for generating a retina mask, separating the retina from the background. Binary erosion and thresholding were then applied. The images were converted to grayscale and float format before applying the threshold and a "remove small objects" technique as post-processing. Finally, the Intersection over Union (IoU) metric was calculated.

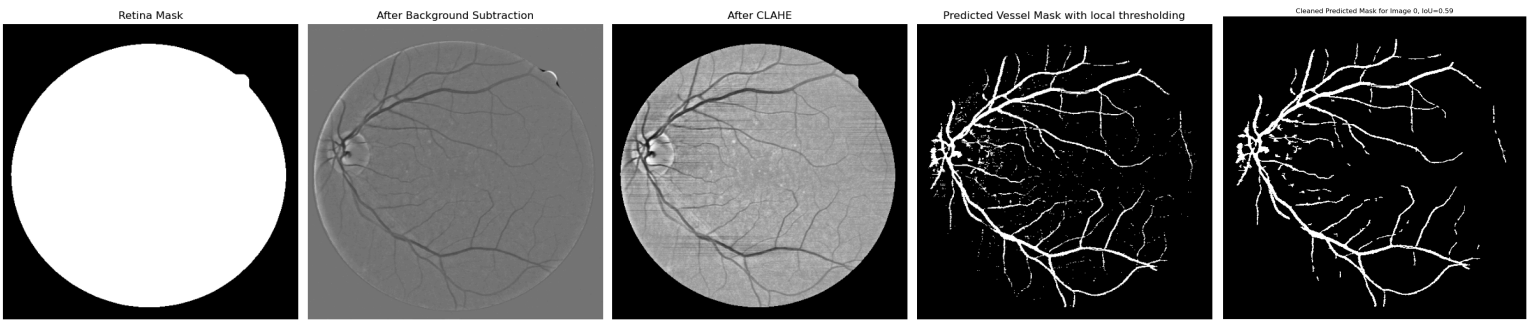
To this code we have applied several techniques to enhance the initial result:

- **Post-processing**: several post-processing techniques have been tried such as binary_fill_holes or dilation. The results got better after applying the dilation **(1)**.
- **Channel choice**: instead of just converting the image to black and white, it was decided to test the IOU with the possible options of the three layers (Black and White, Red, Green and Blue) to analyze which one provided a better contrast of the vessels. The green channel was selected **(2)**, due to the fact that the contrast among vessels and background was higher and a better IOU was provided.
- **Preprocessing:** inside the preprocessing, several techniques were tried such as tuning the gaussian sigma or applying a simple median filter with no improvement but for a sigma of 2 for the first one **(3)**.
- **Local thresholding**: median local thresholding instead of gaussian improved the IOU to 0.46 **(3)**. Then, several block sizes, thresholding values and post-processing techniques were tried with no improvement.
- **CLAHE**: normalization was applied and the parameters of the equalize_adapthist were tested **(4)**.

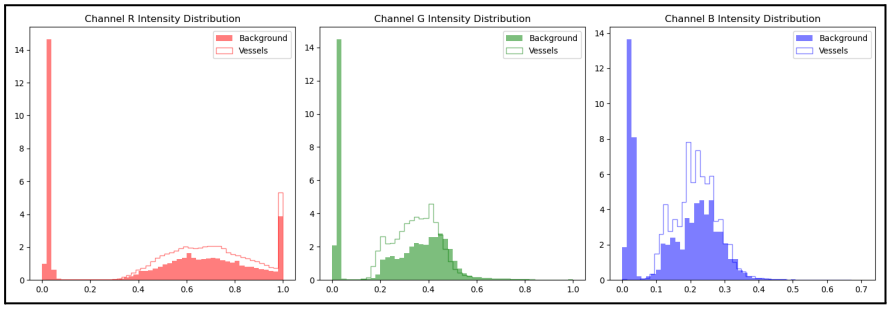
After this, several matters arise. How can the darker circle that tends to show be cleaned? How may the edges of the retina be avoided to be detected as part of the vessels?

Different types of normalization came to play in order to deal with this. Normalization by the median (the median filter of a certain size is subtracted to each pixel) was considered because it improved the blood vessels visualization a lot.

Firstly, this normalization was applied to each image *(see image at the left)* and after the CLAHE, the contrast between the vessels and the rest of the image was really enhanced as some of the noise was removed. After doing this, again the parameters were tuned, mainly the threshold and the block size. With this we have arrived at the best result we have obtained: 0.53 **(6)**.

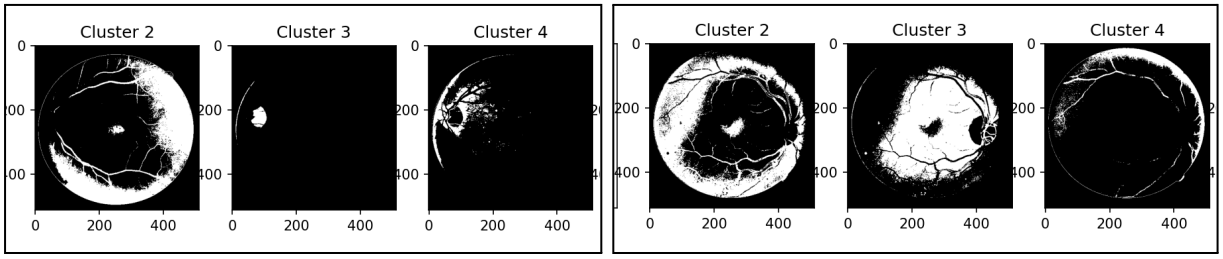


Furthermore, it was also considered extracting some statistics from the testing images so that there could be some learning from the training images. It was tried with the mean and standard deviation of the blood vessels and background and then with the neighborhood mean per pixels together with ratios and percentiles, but again, no improvement was obtained due to the fact that many pixels for background were taken as vessels and many vessels were left out by using just statistics **(7)**.



2.2. Clustering

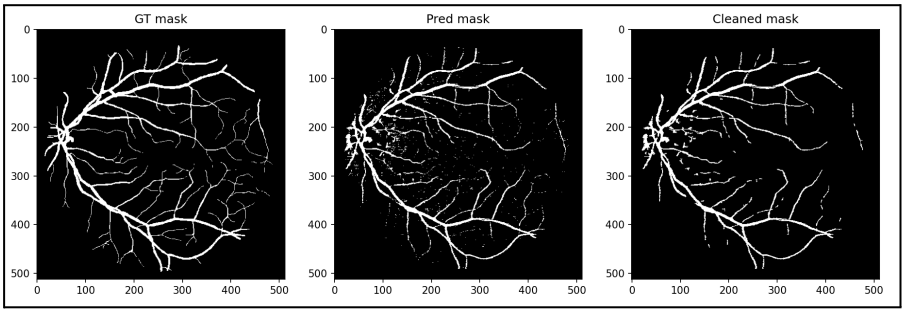
For clustering, we selected the k-means technique, as others such as spectral clustering did not lead to better results because of the nature of the technique itself. Initially, we applied a basic k-means algorithm with k=2 **(8)**, which resulted in a low IoU score of 0.1. Upon examining the clusters, we observed that the optimal cluster varied for each image. To address this, we implemented a loop that treated each cluster as a potential mask. Post-processing techniques were then applied, where we fine-tuned the combination of methods—ultimately choosing **remove_small_objects** and **dilation**. We calculated the IoU for each masked cluster, allowing us to identify the best-performing cluster for each image **(9)**.



For instance, in the first image, cluster number 2 is the best, while in the other image, it is cluster 4. This approach provided a noticeable improvement, raising the IoU to 0.18. Using this logic, our next step was to fine-tune the value of k **(10)**. We tested various values ranging from 2 to 10, finally finding that k=4 produced the best results, leading to a final IoU score of 0.20.

3. Conclusion

In this lab, we aimed to improve retinal blood vessel segmentation, starting with a base code. We have explored several techniques such as hyperparameter tuning, channel selection, trying post-processing techniques, etc. We also experimented with k-means clustering, which was less effective than thresholding techniques. Finally, the best results were achieved through median normalization combined with hyperparameter selection, leading to an **IoU score of 0.53**. Below is an example of a resulting mask:



4. Table of results

Description of approach	IOU obtained
0) Provided one	0.38
1) Changing post-processing	0.40
2) 1 + Green channel	0.42
3) 2 + gaussian sigma = 2 and median local thresholding	0.46
4) CLAHE personalization	0.47
6) Median filter normalization + parameter testing	**0.53**
7) 2 + Using stats for thresholding	0.10 - 0.20
8) Clustering initial	0.10
9) Clustering with cluster selection	0.18
10) Cluster with tuned k parameter	0.20

In green, threshold approaches. In blue, clustering approaches. In yellow, the approach with the highest IOU.