ELL715
Assignment 5 Report

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1 Wavelet

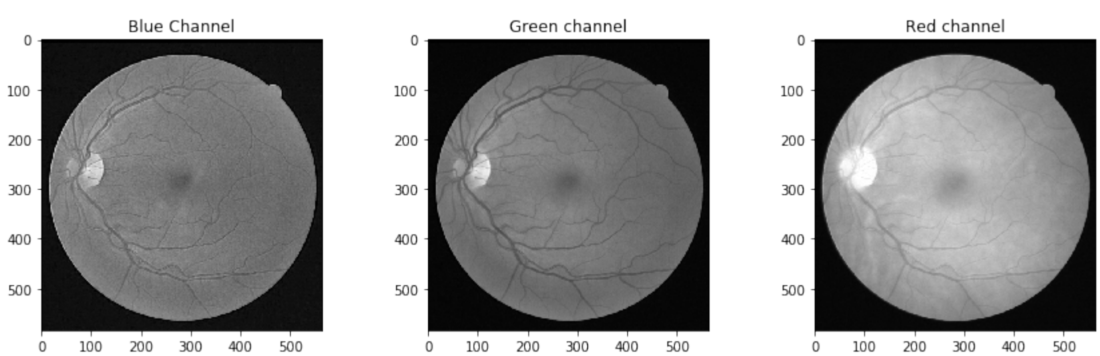
1.1 Original Image

Figure 1: Image Size: $565 * 584$

1.2 Procedure

1.2.1 Extraction of channel

At first the original fundus RGB image is taken and its corresponding red, green and blue channels are extracted. Then, the green channel is taken as it exhibits best contrast as compared to red and blue channel.



(a) Blue channel (b) Green channel (c) Red channel

Figure 2: Images showing different channels, in grayscale, corresponding to the input image

1.2.2 CLAHE

After this, we applied contrast limited adaptive histogram equalization (CLAHE) on the green channel to adjust the non-uniform illumination. The output of the same is:

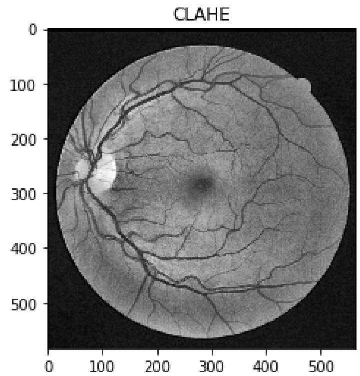


Figure 3: Output of applying CLAHE on green channel

1.2.3 Gabor

Then, we use gabor wavelets. Gabor wavelets used:

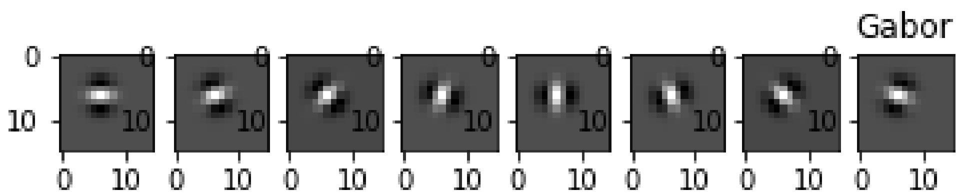


Figure 4: Gabor wavelets

After using Gabor, we obtain the following image:

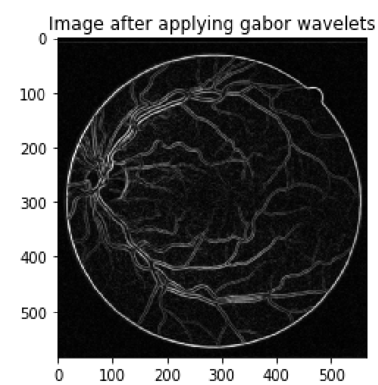


Figure 5: Gabor Output on CLAHE image

1.2.4 Hysteresis

In hysteresis, we have two thresholds: L and H.

- Any edges with strength $< L$ are discarded.

- Any edge with strength $> H$ are kept.
- An edge P with strength between L and H is kept only if there is a path of edges with strength $> L$ connecting P to an edge of strength $> H$.

Output of applying hysteresis on above (gabor output) image:

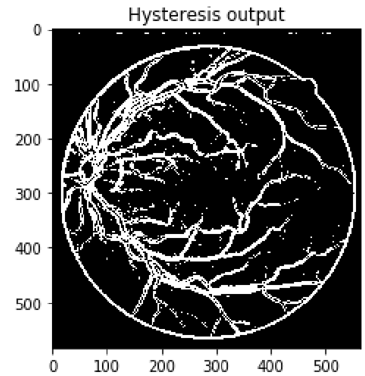


Figure 6: Gabor Output on CLAHE image

1.2.5 Area-based Cleaning

Now, note that in the above output, there are some isolated regions which are misclassified as vessel pixels. These misclassification can be removed by calculating the area of each connected region and considering that if the area is less than 25 (a hyper-parameter) then it can be marked as non-vessel, and hence removed.
Output of applying above area-thresholding on the hysteresis output:

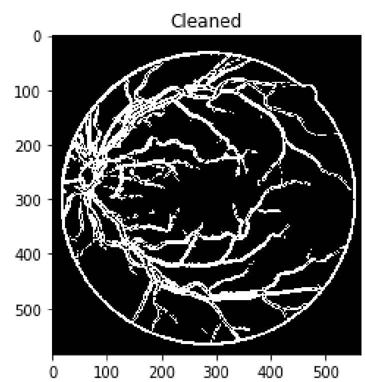


Figure 7: Removing pixels based on area spanned

1.2.6 Closing

Finally, note that there are some "holes" in the vessels in the above output. We observe that the vessels may have some gaps which can be filled by using morphological filling operation that fills some holes in the obtained binary image. We have used the "closing" morphing operation for this purpose.
The structuring element used:

$$\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

The final image, the output of applying the closing operation on area-based cleaned image is:

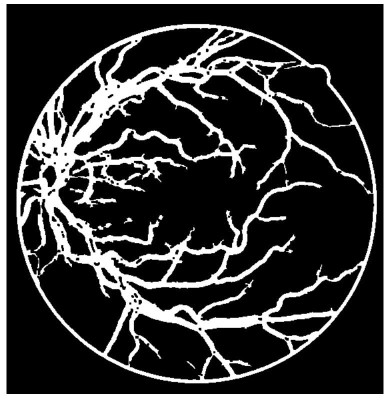


Figure 8: Final output obtained after closing operation

2 Sobel Operator

Here again, we separate the green channel first. Then, we use $3 * 3$ Sobel operator on this image. Output of Sobel operator:

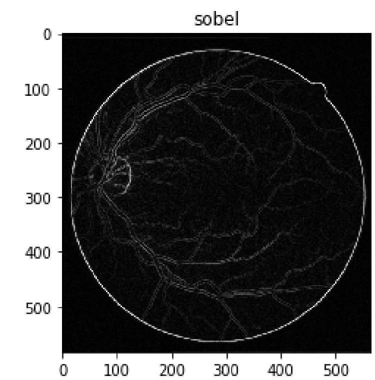


Figure 9: Sobel output

Then, as described above, we apply Hysteresis on the above image to obtain the final image:

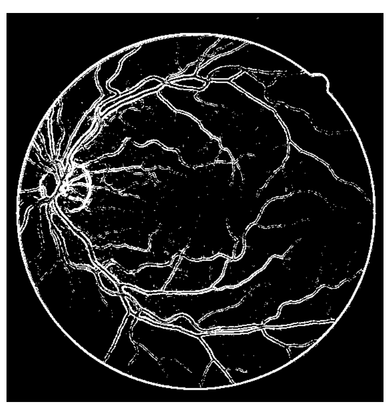


Figure 10: Final output obtained after Hysteresis on Sobel output

3 LoG Operator

Here again, we separate the green channel first. Then, we use $3 * 3$ gaussian smoothing operator on this image, followed by the laplcian. Output of LoG operator:

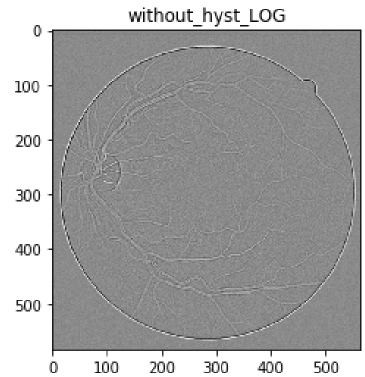


Figure 11: LoG Operator output

Then, as described above, we apply Hysteresis on the above image to obtain the final image:

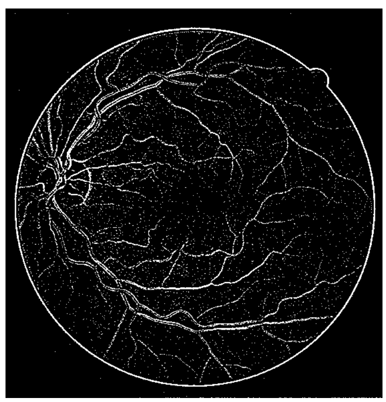


Figure 12: Final output obtained after Hysteresis on LoG output

4 Comparison

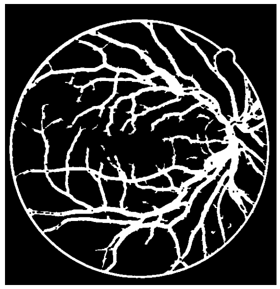
- We note that using wavelets was the **best** method for retinal blood vessel extraction. There are slightly thickened vessels in output compared to the ground truth, but it is most likely due to the morphing operations used. Note that the morphing operation was necessary, since it helped with the "holes" in the output (vessels).
- After wavelets, we observed that using Sobel operator was the **second best** approach. It gives slightly thin vessels compared to ground truth, but as a drawback compared to the wavelet method, it misses out on a few blood vessels.
- Finally, LoG operator was the most **under-performing** method. It gives very thin vessels in output, some of which too thin that they aren't even instantly recognizable. Like Sobel, it also misses out on a few vessels, the reason being similar to what's just mentioned - too thin output.

Thus, we think Wavelets should be the best method for extraction of retinal vessels, followed by Sobel and LoG.

5 Additional Images (Extra Credit)

For all of the following images, in each row, from left to right, we have input image, wavelet-based output, sobel-based output and LoG-based output respectively.


(a)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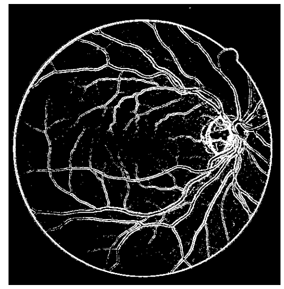
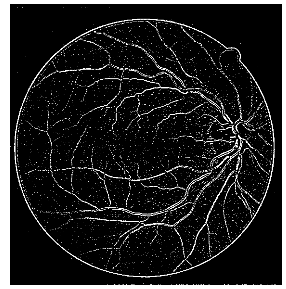

(c)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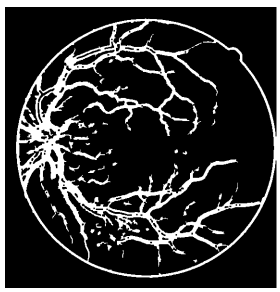
(a)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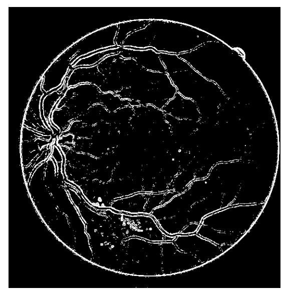
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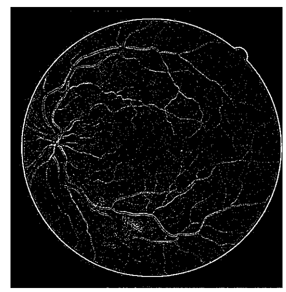
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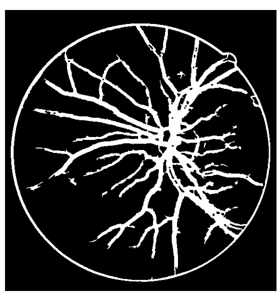
(a)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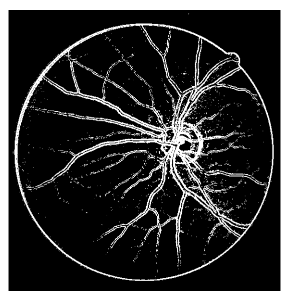
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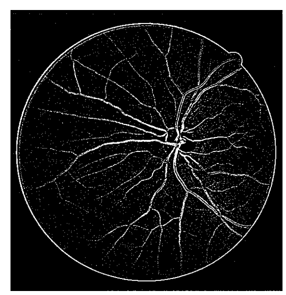
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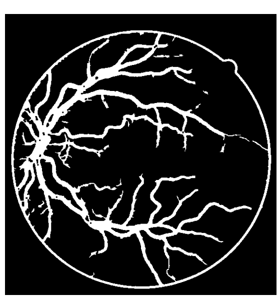
(a)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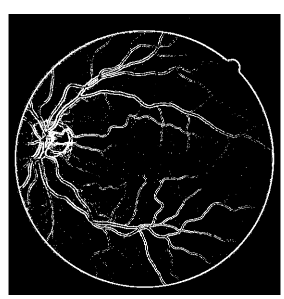
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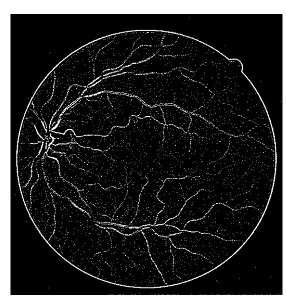
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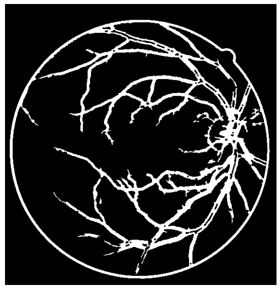
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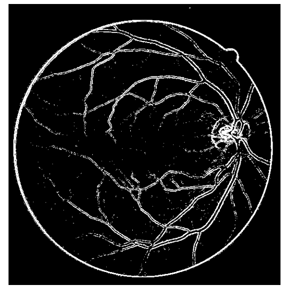
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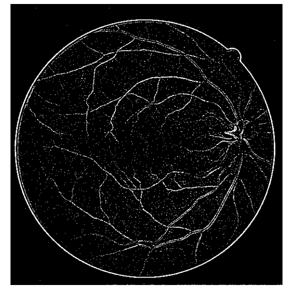
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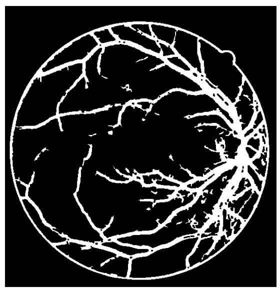
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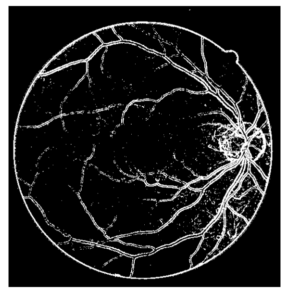
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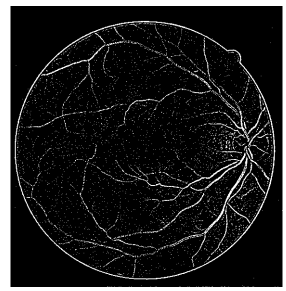
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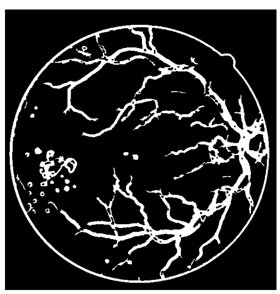
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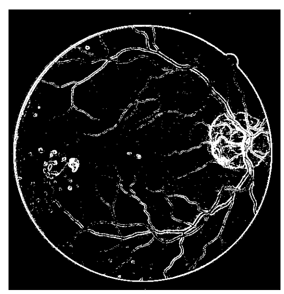
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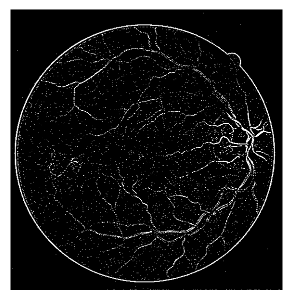
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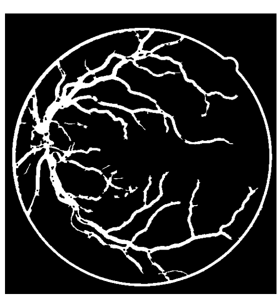
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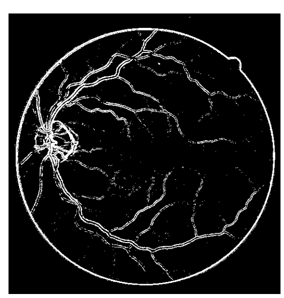
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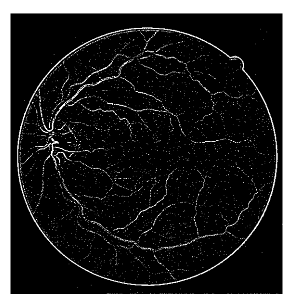
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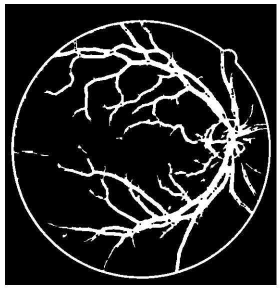
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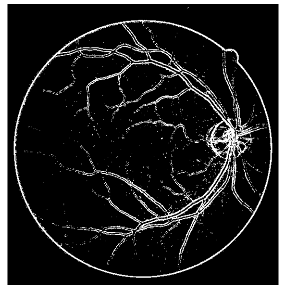
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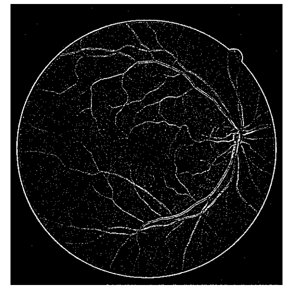
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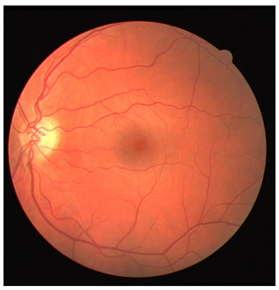
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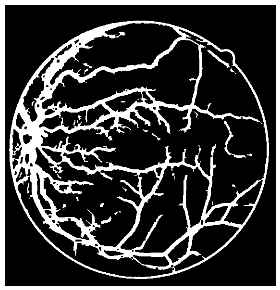
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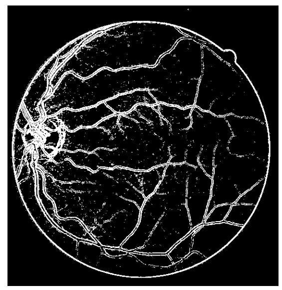
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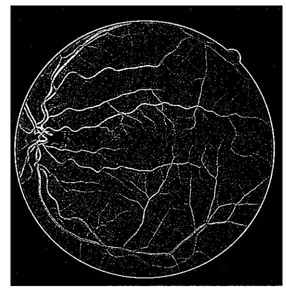
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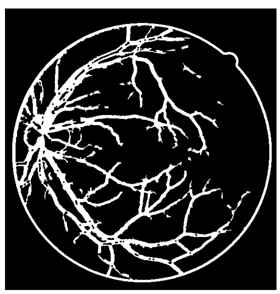
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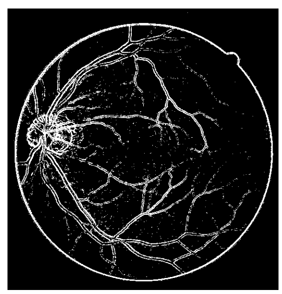
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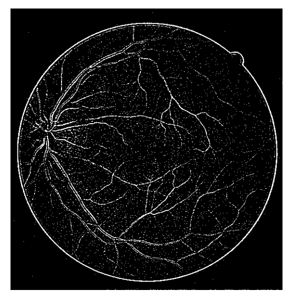
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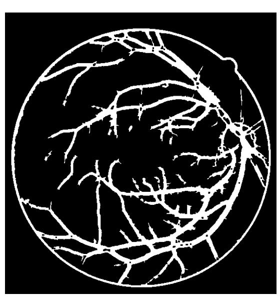
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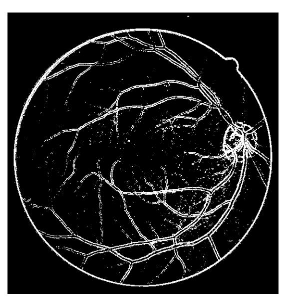
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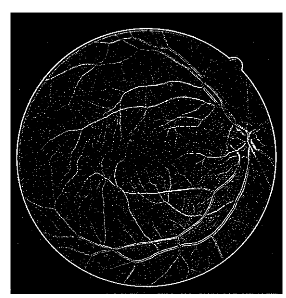
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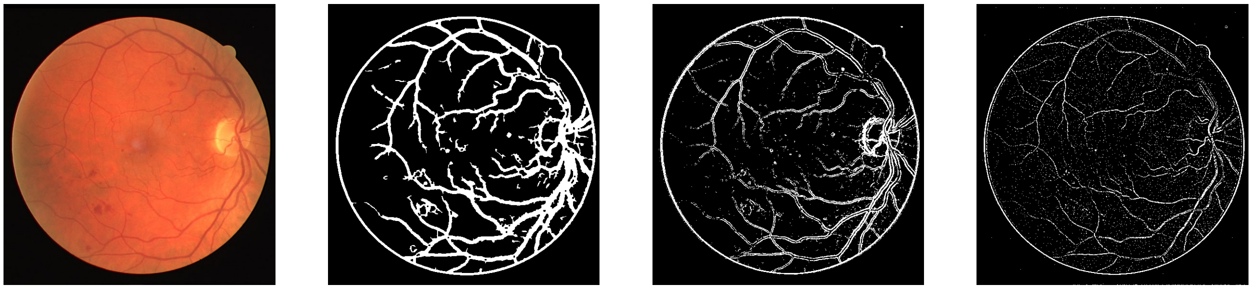

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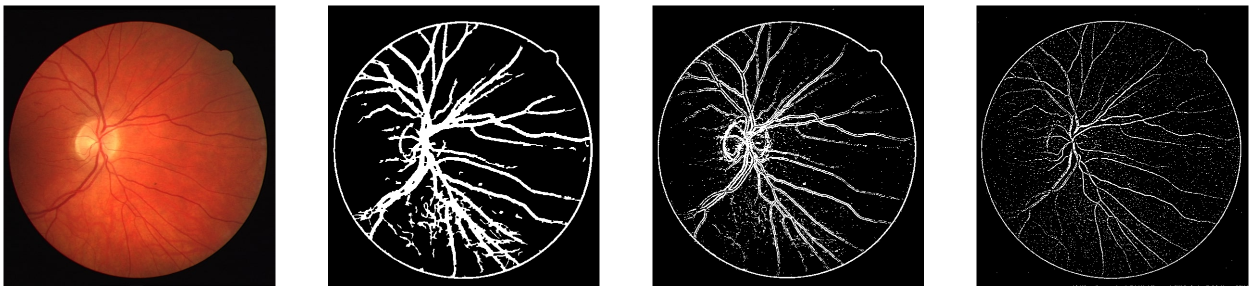

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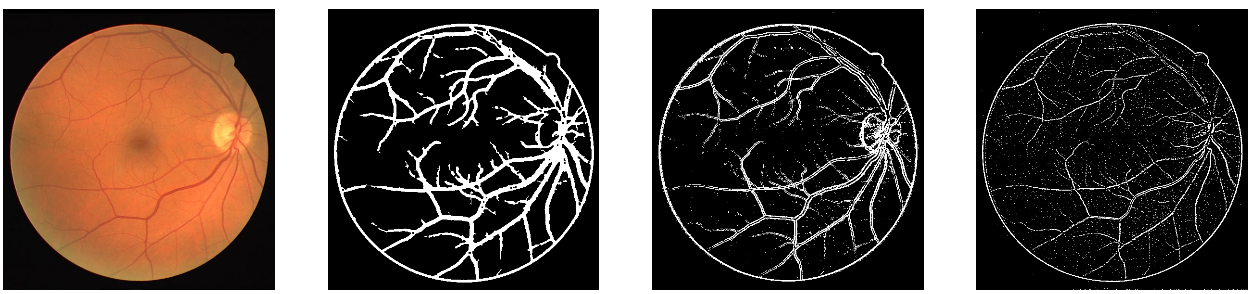

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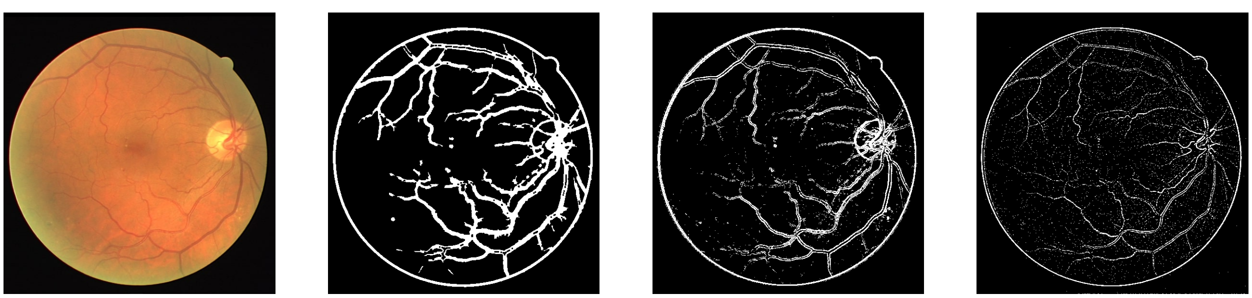

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 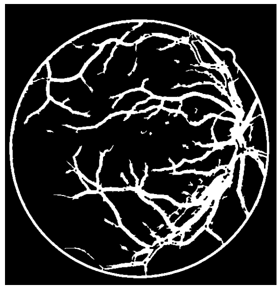 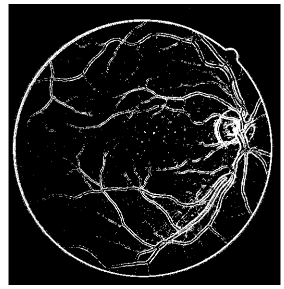 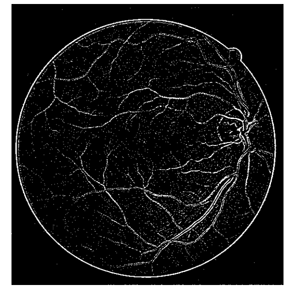

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 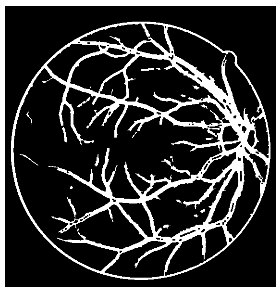 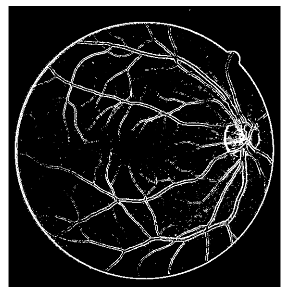 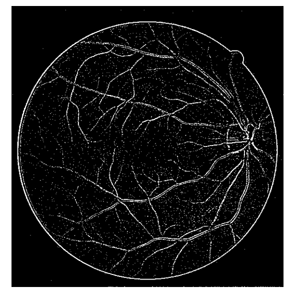

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 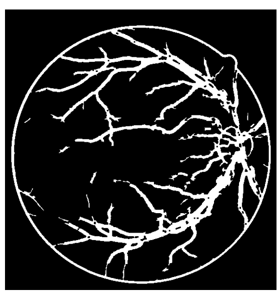 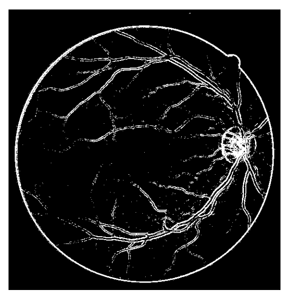 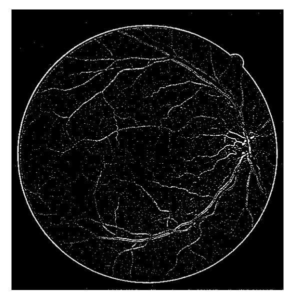

(a) (b) (c) (d)

Figure 13: Results corresponding to images 2.tif to 20.tif

6 References

- https://www.programcreek.com/python/example/89353/cv2.createCLAHE
- https://answers.opencv.org/question/168281/calculating-image-moments-after-connected-component-labeling-function/
- https://scikit-image.org/docs/dev/auto_examples/filters/plot_hysteresis.html
- https://www.researchgate.net/publication/308581077_Retinal_blood_vessel_extraction_using_wavelet_transform_and_morphological_operations
- https://www.researchgate.net/publication/232655219_Blood_Vessel_Enhancement_and_Segmentation_Using_Wavelet_Transform