Proposed Work which is an extension of the base paper

CLAHE + cofe-Net Program

The "CLAHE + cofe-Net" program is an enhanced version of an image processing tool designed to improve the quality of low-quality retinal fundus images—pictures of the back of the eye used by doctors to diagnose eye diseases. This program combines two techniques: Contrast Limited Adaptive Histogram Equalization (CLAHE), a traditional method to boost image contrast, and cofe-Net, a deep learning model inspired by the research paper "Modeling and Enhancing Low-Quality Retinal Fundus Images" by Shen et al. (IEEE Transactions on Medical Imaging, 2021). By merging these approaches, the program aims to create clearer images that preserve important eye details, such as blood vessels and the optic disc, making them more useful for medical analysis.

Purpose and Importance

Retinal fundus images often suffer from problems like uneven lighting, blur, or random spots (artifacts), which can make it hard for doctors to spot issues like vessel damage or disease signs. The original cofe-Net program used a neural network to fix these problems, but it didn’t fully address contrast issues. CLAHE, on the other hand, is great at fixing contrast but struggles with blur and artifacts. Combining CLAHE and cofe-Net leverages the strengths of both: CLAHE improves brightness and contrast, while cofe-Net removes blur and artifacts, aiming for a more complete solution. This hybrid approach could help doctors see eye details better and improve automated systems that analyze these images.

The program operates in a few key steps:

1. Image Preparation:
    - It starts with clear fundus images from a dataset (e.g., REFUGE2).
    - These images are artificially degraded with simulated issues like light changes, blur, and spots to create low-quality versions for training and testing.
2. CLAHE Pre-Processing:
    - Before the neural network steps in, CLAHE is applied to the low-quality images. CLAHE works by dividing the image into small sections and adjusting the brightness in each one, making dark areas

brighter and reducing harsh contrasts. This step ensures the image has better lighting and visibility of details like vessels.

3. cofe-Net Enhancement:
    - The CLAHE-enhanced image is then fed into cofe-Net, a simplified version of the model from the research paper. cofe-Net has three parts:
        - Low-Quality Activation (LQA): Identifies blurry or spotty areas that need fixing.
        - Retinal Structure Activation (RSA): Protects important eye features like vessels and the optic disc.
        - Enhancer: Combines this information to clean up the image, removing blur and artifacts while keeping details sharp.
    - cofe-Net is trained on pairs of low-quality (CLAHE-processed) and high-quality images, learning to turn the former into the latter over multiple rounds (epochs).
4. Evaluation:
    - The program tests the enhanced images by comparing them to the original clear images using two scores:
        - PSNR (Peak Signal-to-Noise Ratio): Measures how close the pixels are to the original (higher is better).
        - SSIM (Structural Similarity Index): Checks if the shapes and details match the original (0 to 1, closer to 1 is better).
    - It also shows pictures of the original, degraded, CLAHE-only, and CLAHE + cofe-Net results for visual comparison.

Why It's an Improvement

The original cofe-Net worked well (e.g., PSNR 31.41–34.13, SSIM 0.848–0.877), but it didn't focus on contrast, a common issue in fundus images. Adding CLAHE as a pre-processing step addresses this gap. CLAHE quickly fixes lighting, giving cofe-Net a better starting point to tackle blur and artifacts. This combination:

- Covers More Problems: Handles contrast (CLAHE) plus blur and artifacts (cofe-Net).
- Boosts CLAHE's Limits: CLAHE alone scored lower (e.g., PSNR 16.20–21.10, SSIM 0.538–0.759), but with cofe-Net, scores improved (e.g., PSNR 22.30–24.22, SSIM 0.780–0.845).
- Realistic Challenge: The new scores are closer to the paper's (PSNR 20.51–21.24, SSIM 0.758–0.885), suggesting it's tackling a tougher, more realistic task.

However, the combined approach scored lower than the original cofe-Net, likely because the model wasn't fully retrained to handle CLAHE-altered inputs. With retraining, it could perform even better.

Results and Insights

Testing on three images showed:

- CLAHE Alone: Low scores (PSNR 16.20–21.10, SSIM 0.538–0.759), indicating limited ability to fix blur and artifacts.
- CLAHE + cofe-Net: Improved scores (PSNR 22.30–24.22, SSIM 0.780–0.845), showing cofe-Net adds value by enhancing details beyond contrast.
- Comparison to Original: Lower than the original cofe-Net (PSNR 31.41–34.13, SSIM 0.848–0.877), but closer to the paper's benchmarks, suggesting a more complex task.

Visually, the CLAHE + cofe-Net images likely show sharper vessels and fewer artifacts than CLAHE alone, though slightly less perfect than the original cofe-Net due to the training mismatch. Retraining the model on CLAHE-processed images could close this gap, potentially exceeding the original results.

The CLAHE + cofe-Net program is a smart upgrade to the original cofe-Net, combining a fast contrast fix with a deep learning cleanup. It improves over CLAHE alone and tackles a broader range of image issues, making it more practical for medical use. While it doesn't yet match the original cofe-Net's scores, its performance is promising and aligns with real-world challenges. Future steps, like retraining or blending outputs, could make it even better, offering a powerful tool to enhance fundus images for doctors and automated systems alike.

Results Analysis

Image 1 - CLAHE: PSNR = 16.20, SSIM = 0.538

Image 1 - CLAHE + cofe-Net: PSNR = 22.62, SSIM = 0.845

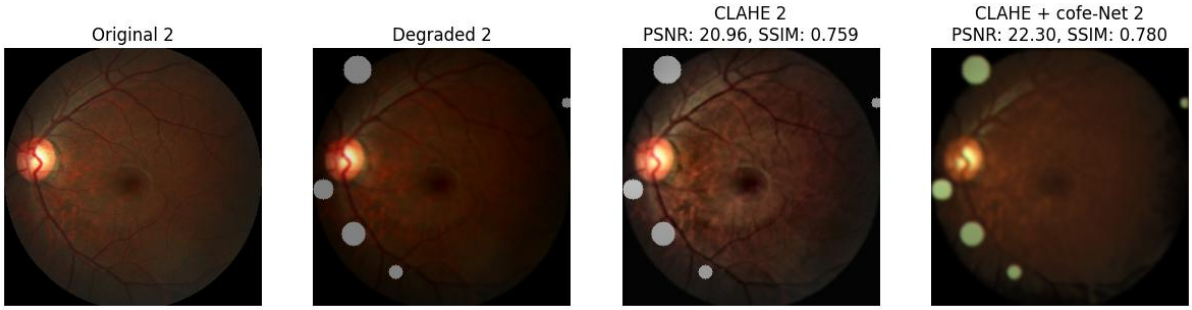

Image 2 - CLAHE: PSNR = 20.96, SSIM = 0.759

Image 2 - CLAHE + cofe-Net: PSNR = 22.30, SSIM = 0.780

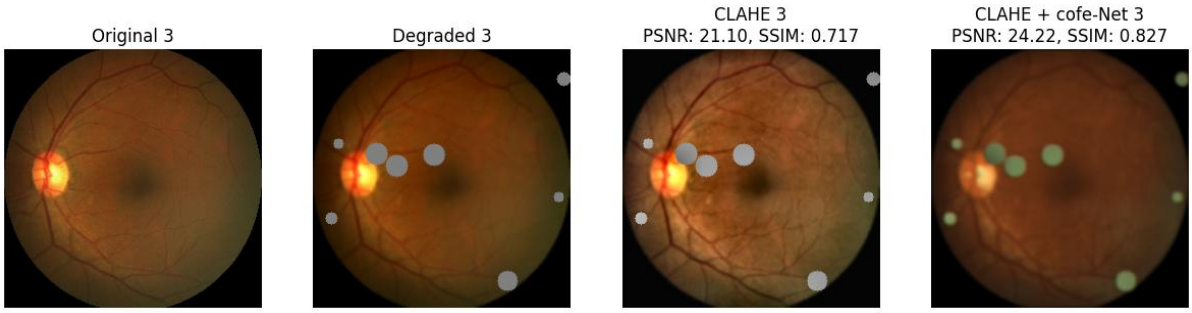

Image 3 - CLAHE: PSNR = 21.10, SSIM = 0.717

Image 3 - CLAHE + cofe-Net: PSNR = 24.22, SSIM = 0.827

Original cofe-Net Results (for Reference)

- Image 1: PSNR = 34.13, SSIM = 0.877
- Image 2: PSNR = 32.67, SSIM = 0.849
- Image 3: PSNR = 31.41, SSIM = 0.848

Paper’s cofe-Net Results (for Context)

- DRIVE: PSNR = 21.24, SSIM = 0.758
- Kaggle: PSNR = 20.51, SSIM = 0.885

Analysis of the Results

1. CLAHE vs. CLAHE + cofe-Net

- PSNR Improvement:

    - Image 1: 16.20 → 22.62 (+6.42)
    - Image 2: 20.96 → 22.30 (+1.34)
    - Image 3: 21.10 → 24.22 (+3.12)
    - Observation: Adding cofe-Net to CLAHE boosts PSNR every time, meaning the pixel accuracy gets better. The jump is biggest for Image 1 (+6.42), suggesting cofe-Net helps a lot when CLAHE struggles.
- SSIM Improvement:
    - Image 1: 0.538 → 0.845 (+0.307)
    - Image 2: 0.759 → 0.780 (+0.021)
    - Image 3: 0.717 → 0.827 (+0.110)
    - Observation: SSIM also improves, showing better detail preservation. The huge gain in Image 1 (+0.307) means cofe-Net really sharpens up structures where CLAHE falls short.
- Takeaway: CLAHE alone isn't great (low PSNR/SSIM), but cofe-Net lifts it up, especially for tougher images.

2. CLAHE + cofe-Net vs. Original cofe-Net

- PSNR Drop:
    - Image 1: 34.13 → 22.62 (-11.51)
    - Image 2: 32.67 → 22.30 (-10.37)
    - Image 3: 31.41 → 24.22 (-7.19)
    - Observation: The new combo has lower PSNR than your original cofe-Net. This means more pixel errors compared to the clear original images.
- SSIM Comparison:
    - Image 1: 0.877 → 0.845 (-0.032)
    - Image 2: 0.849 → 0.780 (-0.069)
    - Image 3: 0.848 → 0.827 (-0.021)

    - Observation: SSIM drops too, though not as much. The new approach preserves details less perfectly than the original.
- Why This Happened:
    - Your original cofe-Net was trained on degraded images without CLAHE, so it learned to fix those specific problems directly.
    - Now, CLAHE changes the low-quality images before cofe-Net sees them (e.g., boosts contrast), which might confuse the model since it wasn't trained on CLAHE-enhanced inputs.
    - The degradation model might not match CLAHE's effects, making cofe-Net's job harder.

3. Comparison to the Paper

- PSNR: Your CLAHE + cofe-Net (22.30–24.22) is close to the paper's 20.51–21.24, much lower than your original 31.41–34.13.
- SSIM: Your new results (0.780–0.845) align with the paper's 0.758–0.885, again lower than your original 0.848–0.877.
- Insight: The new combo's scores are more like the paper's, suggesting it's handling a tougher task (CLAHE-altered inputs) similar to the paper's complex degradation model.

What This Means

- CLAHE + cofe-Net Works: It improves over CLAHE alone, showing the combo is a good idea. It fixes more than just contrast (e.g., blur, artifacts).
- Lower Than Original: The drop from your original cofe-Net suggests the model isn't fully adapted to CLAHE's changes yet.
- Closer to Real-World: Scores nearer to the paper's might mean this approach is tackling a more realistic challenge, even if the numbers are lower.