Quality Assessment and Enhancement of Retinal Fundus Images using Deep Learning Methods

A Thesis submitted by

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Conclusions and Future works

6.1 CONCLUSIONS

This thesis presents novel CNN based methods developed for fundus image quality assessment and enhancement. Following conclusions can be drawn:

First, a new fundus image quality assessment data-set names FIQuA, is prepared. It contains a total of 1500 images along with seven subjective opinion scores for both local and global quality parameters of fundus images. The first six are the opinion scores in the range of [0,10] for six different local quality parameters. These parameters are (1) Visibility of Optic Disc (F1), (2) Visibility of Macula (F2), (3) Visibility of Blood Vessel (F3), (4) Color (F4), (5) Contrast (F5), (6) Blur (F6). The last one is the overall image quality (i.e., good, fair, or poor), provided by the ophthalmologists. The statistical analysis of the above mentioned data indicates that the highest preference is given to the Visibility of Macula (F2) and Color (F4) parameters while judging the fundus image quality. Also, the Visibility of Optical Disc (F3) and Visibility of Blood Vessels (F1) quality parameters are given the least preference by the doctors.

Second, a novel CNN model for fundus image quality assessment is presented. The uniqueness of the proposed model is that it follows an assessment approach similar to the ophthalmologist. It first derives the *six* quality scores (F1-F6), and based on these scores, it classifies the image into a quality class. The proposed model contains two blocks. Block-1 is trained against the six subjective scores taken from the FIQuA data-set using four pre-trained CNN models: Inception-V3, ResNet-151, DenseNet-121, and Xception. Next, the optimized features obtained from these four models are concatenated and transferred to Block-2 to assign the image an appropriate quality label. The results indicate that the proposed CNN model achieves a high correlation with subjective values. The correlation values obtained from CNN Block-1 for SROCC, LCC, and KCC for each quality parameter (F1-F6) are approximately *0.941*, *0.954*, and *0.853* respectively, and for RMSE the result is *0.401*. Further, using the derived ensembled features, the classification accuracy achieved by the CNN Block-2 is *95.66%*. The obtained results show that the appropriate subjective opinion scores of local quality parameters help to achieve a high classification accuracy.

Lastly, a UNet-based architecture residual-densely connected UNet (RDC-UNet) is proposed for the task of fundus image enhancement. Initially, a total of five common degradations occurring in fair quality fundus images were identified: (i) uneven illumination over macula (MUI), (ii) uneven illumination over border region (BUI), (iii) bright, (iv) dark, and (iii) haze. Algorithms are proposed to manually create similar distortions in fundus images. A total of 1000 good quality images were randomly chosen as reference images from the EyeQ data-set. Thereafter, using the proposed algorithms, a data-set of 14000 degraded fundus images resembling the distortions mentioned above were created using these reference images.

Now, using UNet as backbone architecture, we proposed exploiting the capabilities of residual and dense connections for the enhancement task. Here, as compared to other UNet based works, our RDC-UNet effectively utilizes the virtues of bottleneck layer using RDC blocks. Another peculiarity of the proposed model is that it is trained over synthetically generated distortions and tested over the naturally generated distortions. The RDC-UNet consists of two training phases. In the first phase it is trained individually for each of the five manually generated distortions. Now, the second phase of training is done to effectively address the presence of multiple such distortions present in naturally degraded fundus images. The second phase consists of training a proposed ensemble learning-based model built using the five individually trained RDC-UNet models. The enhancement results obtained over both synthetically and naturally degraded fundus images indicate that the proposed model is able to effectively suppress the presence of frequently appearing distortions in the fundus images. The effectiveness of the proposed model is also demonstrated with the help of objective quality evaluation and blood vessel segmentation application.

6.2 RECOMMENDATIONS FOR FUTURE WORK

Acquiring fundus images via a smartphone and a condensing lens is called smartphone fundoscopy. This setup creates a digital image of the fundus by using the coaxial light source of the phone. However, such images are more vulnerable to various distortions. To address such challenges, we aim to apply the contributions of the Thesis. A brief introduction to the smartphone funduscopy, related challenges, and the utility of the contributions of this Thesis to address the challenges is provided below:

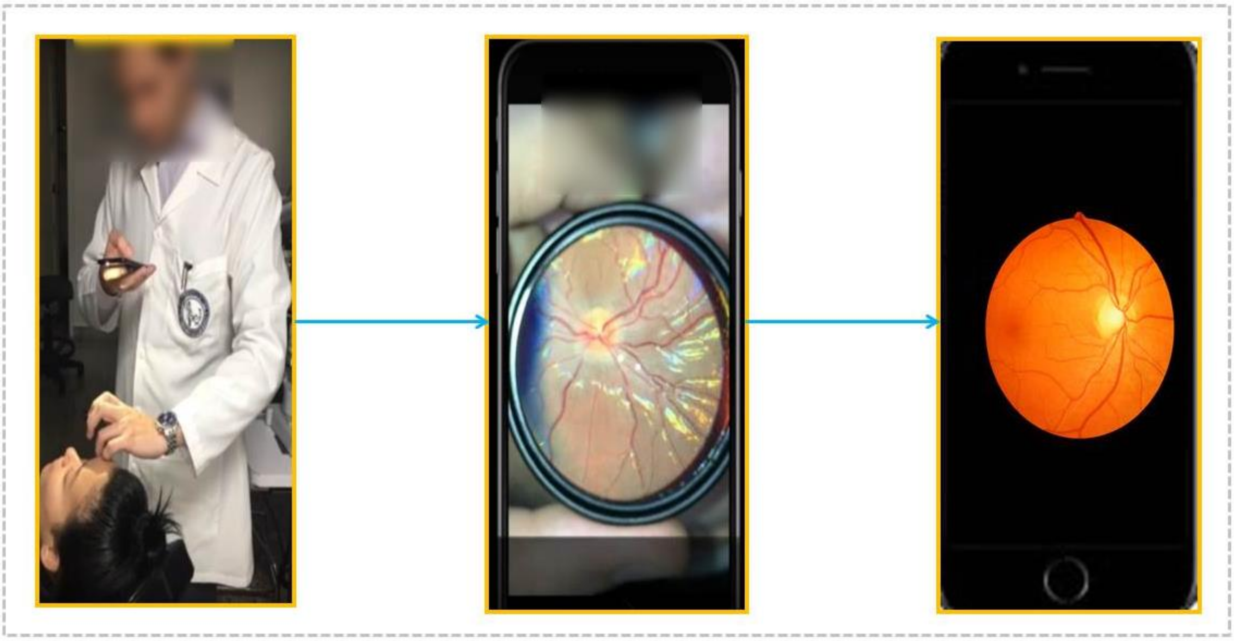

Figure 6.1 : An example of the fundus image acquisition process through smartphone funduscopy Espinosa [2022]

6.2.1 Smartphone Funduscopy:

The main idea is to use the smartphone screen rather than a binocular indirect ophthalmoscope to conduct a fundus examination. The process of fundus image acquisition through smartphone funduscopy is shown with the help of Fig. ?. A 20 or 28 diopter lens is required, along with a smartphone that will work as a light source, ophthalmoscope, and acquisition device. There are numerous benefits of smartphone funduscopy. The smartphones are equipped with a light source, provide access to networks for data transmission, are portable, and are ubiquitous. For example, in the case of examining a young child or a patient who cannot make a movement to get into a good position for conventional funduscopy, smartphone funduscopy provides great assistance. However, it comes with a few limitations and challenges:

- **Field of View:** The peripheral view of the retinal is smaller. In other words, in comparison to the conventional setup, smartphone funduscopy has limited access to the retinal. However, it has been found that they are sufficient for glaucoma and diabetic retinopathy screening [Giardini *et al.* [2014]; Russo *et al.* [2015]].

- **Image Quality:** Although, the camera quality of today's smartphone is significantly high. However, various external factors, including occlusion of eyelashes, improper light exposure, glare, lack of training, etc., severely affect the quality of the fundus image. Additionally, taking a screenshot of the captured video can also further reduce the image quality. Therefore, compression is also an essential factor to be considered in the case of smartphone funduscopy.

- **Acquisition Training:** Due to its portable nature, the smartphone technique includes several moving parts like a doctor, camera, lens, and patient. Therefore, a reasonably polished skill set is required to capture a good fundus photograph.

There exist many areas in which fundus photography is required: the emergency department, nursing homes, the clinic, remote area hospitals etc. However, the current gold standard is the fixed setup tabletop fundus camera. It is bulky and expensive and requires an immobile patient to be seated still. The advancement of the high-resolution smartphone addresses these challenges by providing a highly adaptive way for fundus photography. However, this technique lacks in ensuring the image quality for a reliable diagnosis. The proposed methods for fundus image quality assessment and enhancement can be highly beneficial to resolving the quality issues in smartphone captured fundus images. In future work, we aim to work on mobile application based solutions to diabetic retinopathy using smartphone funduscopy.

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