Single Retinal Image Restoration

Appendix

Impact

1. Scope of this thesis

In this thesis, we propose to use non-deep-learning-based methods to achieve single retinal image restorations tasks. These tasks are categorized into (1) retinal image illumination correction; (2) cataractous retinal image dehazing; (3) retinal image blind-deconvolution. We designed comprehensible algorithms to bring the degraded retinal image back to high-visual quality. The scientific and social impacts are highlighted here.

2. Scientific Impact

The chapters have been published in peer-reviewed scientific journals and presented at (inter)national conferences. They contribute to research in the field of ophthalmology, mathematics, and the ophthalmic photography community.

(1) **Better physical(optical) model.** The first scientific impact is our double-pass fundus reflection model, which enables modeling image formation in retinal photography physically and mathematically correct.

(2) **State-of-the-art enhancement ability.** Following (1), the second scientific impact is the ability of our model to tackle cataractous retinal images. Our algorithm significantly improves the visual quality of hazy retinal images which has great potential in clinical applications. Our research got noticed by the Ophthalmic Photographers' Society and the author was invited to present his works in an oral presentation in ICOP 2023.

(3) **Reveals deep relationship between different image processing tasks.** Our contribution to using image denoising to achieve image dehazing/illumination correctly unifies three classical image processing tasks into a single framework, which can further bring new scientific research topics to the image processing community.

(4) **New retinal image deconvolution algorithm.** We first demonstrated the embedded illumination correction for retinal image blind deconvolution, which outperformed other state-of-the-art methods.

(5) **User-friendly designing.** Most of our models adaptively adjust the model parameters according to the input images. This allows user-friendly designing of software for people who are not familiar with image processing.

(6) **Safe and reliable.** We are not using a deep-learning model to tackle the retinal image restoration, but take an analytical approach, which allows each step as well as intermediate outcomes of the algorithms can be understood by users. As such, we believe that our models are safer, more interpretable, and more reliable than deep-learning methods, that act as black boxes between input and output.

3. Social Impact

A fundus camera is a basic device that is not only used in every eye clinic, but also more generally, such as in general practice and by optometrists where it is used in areas including but not limited to education, research, and diagnosis. Digital retinal image restoration provides a simple and cheap way to increase the image quality of every fundus camera and as such our restoration models have the following social impacts:

Early detection of eye diseases

The retinal image enhancement algorithm can improve the quality of images taken of the eye, making it easier for doctors to identify early signs of eye diseases such as glaucoma, macular degeneration, and diabetic retinopathy. Early detection of findings through cataractous retinal images may improve the outcome of treatment of retinal diseases, and influent the decision-making on surgery that might in some cases even be not necessary. For example, patients with severe cataracts might also have macular degeneration. In these cases, if the macular degeneration can be observed through enhanced cataractous retinal image, ophthalmologists are able to choose a better treatment plan to minimize risks and stress for patients.

Access to healthcare

The high cost of equipment and lack of trained professionals can limit access to techniques of retinal imaging, particularly in low-income and rural areas. By developing novel image processing algorithms that can enhance retinal images, this research can potentially reduce the need for expensive equipment and trained professionals, making retinal imaging more accessible and affordable for patients in these areas.

Additionally, our research can contribute to the development of telemedicine applications for retinal imaging. Telemedicine enables remote consultation and diagnosis of patients by healthcare professionals, which can be particularly beneficial for patients in rural or remote areas who may not have access to specialized medical care. By enhancing the quality of retinal images, this research can improve the accuracy of telemedicine diagnosis, reducing the need for patients to travel long distances for medical appointments.

Furthermore, our research can also contribute to the development of mobile health (mHealth) applications for retinal imaging. These applications can enable patients to take retinal images using their smartphones or other mobile devices, which can be sent to healthcare professionals for diagnosis. By developing image processing algorithms that can enhance the quality of these images, our research can potentially improve the accuracy of diagnosis through mHealth applications, making healthcare more accessible and affordable for patients.

Better surgical outcomes

The retinal image enhancement algorithm can help ophthalmologists obtain clearer images of the eye during surgery, which can help improve surgical outcomes and reduce the risk of complications.

Further, during retinal surgery, obtaining a clear and detailed image of the eye is essential for accurate diagnosis and treatment. Our image restoration algorithm can enhance the clarity and detail of retinal images, which can help ophthalmologists visualize the structures of the eye more clearly during surgery. This, in turn, can improve surgical outcomes and reduce the risk of complications.

Improved visualization can also help ophthalmologists identify and avoid critical structures, such as blood vessels, during surgery, which can further reduce the risk of complications and improve patient safety.

Collaboration research

During the development of the algorithms in this thesis, the author collaborated with researchers from the Vitreo-Retinal Surgeon in India, the Technology University of Eindhoven, and OiVi from Norway. He has established a network of experts with diverse backgrounds, skills, and perspectives, which enriched our research and led to new ideas and innovations including investigation of new retinal image processing methods, solving practical clinical problems, and commercialization of algorithms.

The author presented research at high-level conferences in the fields of optics, biomedical science, and ophthalmology, including ARVO (The Association for Research in Vision and Ophthalmology), SPIE Photonics Europe, and ICOP (International Conference on Ophthalmic Photography). These presentations generated significant interest and discussion around the research presented in this thesis, contributing to the broader dissemination of knowledge and potential collaborations with other researchers and institutions.

Economic

As mentioned in **Access to Healthcare**, the research in this thesis has the potential to reduce healthcare costs. Besides this, it can contribute to the development of new medical technologies and products. For example, our image processing algorithm can be integrated into existing retinal imaging equipment, creating a new product that can be sold to healthcare providers. This can generate revenue for companies that manufacture and sell this equipment and create job opportunities in the medical device industry.

Our research can also lead to the development of new telemedicine and mHealth applications, creating new business opportunities for healthcare providers and companies. For example, telemedicine companies can incorporate our image-processing algorithm into their platforms, improving the accuracy of diagnosis and treatment and attracting more customers.

4. Target audience

The first target audiences for this research are academics and researchers in the field of medical image processing, ophthalmology, and computer science. They may be interested in learning about our novel image-processing algorithm and its potential applications in the diagnosis and treatment of eye diseases.

Second, ophthalmologists and healthcare providers who work with patients with retinal diseases may also be interested in this research, since providing clearer and more detailed images of the eye, can help to make more accurate diagnoses and tailor treatments more precisely to each patient's needs. This can lead to better patient outcomes, including improved visual acuity and quality of life.

Last, the medical device industry, including companies that manufacture and sell retinal imaging equipment, may be interested in my research as well. Our image processing algorithm can be integrated into existing equipment or used to develop new products that can improve patient care and generate revenue.