Scalable, Low-Cost, Fast Screening of Retinopathy of Prematurity (ROP)

Abstract

Retinopathy of prematurity (ROP) is a significant cause of blindness in preterm infants globally. Early diagnosis and treatment can reduce its impact. However, the decreasing number of neonatal ophthalmologists, particularly in low- and middle-income countries (LMICs) like India, poses challenges in addressing the rising cases of ROP among high-risk infants. The unbalanced distribution of resources and time constraints further complicate the situation. Traditional ROP screening methods struggle to cope, especially in present circumstances.

Therefore, this thesis proposes an affordable, scalable ROP screening and eye health monitoring solution. Utilizing mHealth, eHealth, Internet of Medical Things (IoMT), and telemedicine, we aim to provide cost-effective ROP screening, diagnosis, and monitoring using digital imaging devices. However, challenges arise from the quality of retinal images in premature infants, affected by various noises and artifacts, including motion blur and uneven illumination. Additionally, underdeveloped retinal landmarks in premature infants complicate the detection and quantification of ROP through retinal scans.

Despite challenges, recent advances in data-driven machine learning (ML) and deep learning (DL) techniques show promise in imaging-based diagnosis and monitoring of diseases, particularly retinal conditions. These methods excel in medical image segmentation, classification, diagnosis, and monitoring of eye diseases. However, developing disease-specific ML/DL models necessitates sufficient labelled image datasets and addresses the explainability issue. Additionally, sharing health information raises data privacy and security concerns, particularly in LMICs, where establishing a reliable healthcare environment is crucial for ensuring people's confidence in sharing health data without security and privacy risks.

Thus, this thesis proposes solutions for early ROP detection and treatment, aiming to reduce healthcare costs and enhance care accessibility in LMICs. Key contributions include:

- **IIRIR dataset**: To facilitate the development and fine-tuning of deep learning models, the thesis introduces a labelled retinal image dataset, the Indian Infant Retinal Image of ROP (IIRIR) collected from AIIMS Delhi.

- **DL-assisted ROP Screening Technique:** This approach utilizes a deep convolutional neural network (DCNN) and computer vision to automatically recognize optical disc (OD) and retinal blood vessels in ROP patients. The system categorizes the severity of ROP (Zone-1), providing a scalable solution for areas lacking large historical datasets.

- **Plus Disease Classification:** Extending the DL-assisted screening technique, the study introduces an analysis of Plus disease, a severe form of ROP. The research explores var-

ious methods to compute and locate blood vessel map features, offering insights into tortuosity and vascular features for better treatment decisions.

- **Device Fingerprint and Image Watermarking-Based Data Provenance Framework:** The thesis also explores a Device Fingerprint (DFP) and Image watermarking-based medical image data provenance framework. This framework ensures data provenance by embedding device attributes into raw images before sharing them with remote experts. The study introduces a DevFing-based daughterboard for DFP generation, employing the concept of Physical Unclonable Function (PUF) to generate a unique device identification based on electrical characteristics.

The proposed approach was empirically validated using preterm infant retinal images from IIRIR image dataset. Experimental results demonstrate robust ROP screening with 96.69% vessel segmentation accuracy and an overall OD detection accuracy of 98.94%. Our system can accurately diagnose ROP in Zone-1 with 88.23% accuracy. For Plus disease screening, various blood vessel map features are computed and analyzed, and the algorithm achieves notable precision in parameter recognition. The study reveals tortuosity indices for Plus, pre-Plus, Healthy infants, and the percentage of severely infected vessels. Finally, the effectiveness of the medical image data provenance framework is evaluated regarding computational time, image quality, security, and trustworthiness. The proposed DFP-based watermarking method significantly improves matching percentage accuracy, strengthening data integrity in the system.