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Improved Multiclass Classification of Eye Diseases using a Feature-Augmented Enhanced Deep Learning Approach

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Improved Multiclass Classification of Eye Diseases using a Feature-Augmented Enhanced Deep Learning Approach

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A thesis submitted

In fulfillment of the requirements for the degree of Master of Science

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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ABSTRACT

Vision impairment is a global health issue often caused by conditions such as cataracts, diabetic retinopathy, and glaucoma. Early detection is critical to prevent irreversible vision loss. Retinal fundus imaging plays a central role in diagnosis, and deep learning offers promising automation for disease detection. However, multiclass eye disease classification remains challenging due to limited annotated datasets, overlapping clinical features and intra-class heterogeneity. This research proposes an enhanced deep learning pipeline for classifying retinal fundus images into four classes: cataracts, diabetic retinopathy, glaucoma, and normal. A dataset, named CDGN, was constructed by integrating and standardizing images from eight publicly available sources, offering improved diversity, resolution, and patient demographics to enhance model robustness and generalizability. Image enhancement was applied to make disease-specific feature more pronounced, while attention mechanisms improved focus on relevant regions, and ensemble learning further boosted performance across heterogeneous data. Multiple convolutional neural network (CNN) architectures were explored through transfer learning. An ablation study quantified the individual contributions of image enhancement, attention, and ensemble learning. Experimental results demonstrate progressive improvements in accuracy, recall, precision, F1-score and AUC across enhancement stages, with the ensemble model achieving the highest performance. These findings indicate that the feature-enhanced deep learning pipeline effectively addresses challenges in multiclass eye disease classification, supporting clinical decision-making and advancing automated diagnostic systems in ophthalmology.

Keywords: Multiclass eye disease classification, retinal fundus images, convolutional neural networks, attention mechanism, ensemble learning

Penambahbaikan Pengelasan Berbilang Kelas Penyakit Mata Menggunakan Pendekatan Pembelajaran Mendalam yang Dipertingkatkan melalui Pengayaan Ciri

ABSTRAK

Kecacatan penglihatan merupakan isu kesihatan global yang sering disebabkan oleh keadaan seperti katarak, retinopati diabetik, dan glaukoma. Pengesanan awal adalah penting bagi mengelakkan kehilangan penglihatan yang tidak boleh dipulihkan. Imejan fundus retina memainkan peranan penting dalam diagnosis, dan pembelajaran mendalam menunjukkan potensi dalam pengesanan penyakit secara automatik. Walau bagaimanapun, klasifikasi penyakit mata pelbagai kelas masih mencabar disebabkan oleh set data beranotasi yang terhad, ciri klinikal yang serupa atau bertindih, serta heterogeniti dalam kelas. Kajian ini mencadangkan satu rangka kerja pembelajaran mendalam yang dipertingkatkan bagi mengklasifikasikan imej fundus retina kepada empat kelas: katarak, retinopati diabetik, glaukoma, dan normal. Satu set data baharu yang dinamakan CDGN telah dibina dengan menggabungkan dan menyeragamkan imej daripada lapan sumber awam yang tersedia, memberikan kepelbagaian, resolusi, dan demografi pesakit yang lebih baik untuk meningkatkan ketahanan dan keupayaan generalisasi model. Penambahbaikan imej telah digunakan untuk menonjolkan ciri-ciri penyakit yang spesifik, manakala mekanisme perhatian meningkatkan fokus pada kawasan imej yang relevan, dan pembelajaran ensembel seterusnya meningkatkan prestasi data yang heterogen. Pelbagai seni bina rangkaian neural konvolusi (CNN) telah diterokai melalui pemindahan pembelajaran. Kajian ablasi dijalankan untuk menilai sumbangan individu penambahbaikan imej, mekanisme perhatian, dan pembelajaran ensembel. Keputusan eksperimen menunjukkan peningkatan progresif dalam ketepatan, kepekaan (recall), ketepatan ramalan (precision), skor F1 dan AUC pada setiap peringkat penambahbaikan, *dengan model ensembel mencatatkan prestasi tertinggi. Hasil kajian ini menyerlahkan keberkesanan rangka kerja pembelajaran mendalam yang dipertingkatkan dengan ciri tambahan dalam menangani cabaran klasifikasi pelbagai kelas penyakit mata, menyokong proses menjana keputusan klinikal dan memacu pembangunan sistem diagnostik automatik dalam bidang oftalmologi.*

Kata kunci: *Pengelasan berbilang kelas penyakit mata, imej fundus retina, rangkaian neural konvolusi (CNN), mekanisme perhatian, pembelajaran ensembel*

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LIST OF ABBREVIATIONS

AI	Artificial Intelligence
ANN	Artificial Neural Network
AUC-ROC	Area Under the Receiver Operating Characteristic Curve
CDR	Cup-to-Disk Ratio
CLAHE	Contrast Limited Adaptive Histogram Equalization
CNN	Convolution Neural Network
COCO	Common Objects in Context
DenseNet	Densely Connected Convolutional Network
DR	Diabetic Retinopathy
FLOPS	Floating-Point Operation Per Second
FN	False Negative
FP	False Positive
ILSVRC	ImageNet Large-Scale Visual Recognition Challenges
ISNT	Inferior, Superior, Nasal, Temporal
LSTM	Long Short-Term Memory
NLP	Natural Language Processing
NRR	Neuroretinal Rim
ODIR-5K	Ocular Disease Intelligence Recognition
ONH	Optic Nerve Head
PCA	Principal Component Analysis
ReLU	Rectified Linear Unit
ResNet	Residual Network
RFMiD	Retinal Fundus Multi-Disease Image Dataset

RGB	Red, Green, Blue
RNN	Recurrent Neural Network
ROC	Receiver Operating Characteristic
SMOTE	Synthetic Minority Oversampling Technique
SNN	Simulated Neural Network
SVM	Support Vector Machine
TN	True Negative
TP	True Positive
VGG	Visual Geometry Group
WHO	World Health Organization

CHAPTER 1

INTRODUCTION

1.1 Background

Vision is one of the most important and dominant senses among the five human senses. It is essentially needed in every aspect of life, giving individuals the ability to see and engage with their surroundings through their eyes. Vision plays an indispensable role in daily activities, such as guiding movement, helping people avoid obstacles, recognising objects, and coordinating actions with remarkable precision. Beyond these fundamental functions, vision opens a world of limitless possibilities. It allows individuals to connect with others on a deeper level, fostering empathy and understanding through subtle cues like facial expressions and body language.

For some individuals, however, this essential sense is either partially or completely diminished, resulting in a condition known as visual impairment. Visual impairment is the term used to describe any eye condition affects the visual system and its function (World Health Organization [WHO], 2023). It can have lifelong adverse effects, making it challenging for individuals to learn, walk, read, and carry out daily activities without vision. Visual impairment covers a range of conditions that affect the visual system, with a spectrum of severity, ranging from mild visual disturbances that can be corrected with spectacles or contact lenses to complete blindness.

According to the World Report on Vision, the first report by World Health Organization (WHO) on global vision health, it is estimated that at least 2.2 billion people worldwide are suffering from some form of visual impairment, and that in at least 1 billion—

nearly half—could have been avoided or are still unresolved (WHO, 2019). Additionally, the report estimates that at least 650 million people globally are living with moderate to severe vision loss. The report identified age-related macular degeneration, cataracts, diabetic retinopathy, glaucoma, and refractive errors as among the leading causes of visual impairment and blindness (WHO, 2019).

Age-related macular degeneration is brought on by the macula's deterioration with aging and is prevalent among individuals aged 50 years and above (Muchuchuti & Viriri, 2023). According to WHO (2019), cataracts is caused by clouding in the eye lens that is due to excess blood sugar, which can happen at any age but are more prevalent in older people. Diabetic retinopathy is complication of uncontrolled, long-term high blood glucose levels, which harms the retina's blood vessels. These blood vessels may become swell, leak, or blocked, leading to vision loss due to swelling in the central part of the retinal. Glaucoma, on the other hand, is an eye disease led by higher-than-normal intraocular pressure which progressively damages the optic nerve (WHO, 2023). Refractive errors are vision disorders that caused by irregularities in the eye's shape or the curvature of the cornea, which interfere with eye's ability to concentrate on objects at varying distances. These errors can be corrected using eyeglasses, contact lenses, or refractive surgical procedures.

In 2020, among 206 million adults aged 50 years and older with moderate to severe vision impairment, the predominant causes included cataract (78.8 million), diabetic retinopathy (2.9 million), glaucoma (4.1 million), refractive errors (86.1 million), and age-related macular degeneration (6.2 million). For the estimated 33.6 million blind adults in the same age group, the primary causes of blindness were cataracts (15.2 million), diabetic retinopathy (0.9 million), glaucoma (3.6 million), refractive errors (2.3 million), and age-