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SmartEye: Self-Supervised AI System for Refractive Error Detection Using Fundus Images

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Abstract

Refractive errors, including myopia and hyperopia, are among the leading causes of vision impairment worldwide. Conventional screening relies heavily on expert evaluation, making diagnosis slow and resource-intensive. This paper presents SmartEye, a self-supervised learning (SSL)–based system designed for automated refractive error detection using fundus images. The proposed method involves image preprocessing, contrastive SSL-based feature extraction, and a fine-tuned Vision Transformer classifier. Experimental results demonstrate that SmartEye achieves over 90% accuracy, outperforming traditional supervised CNN models while requiring fewer annotated samples. Grad-CAM visualizations provide interpretable explanations by emphasizing relevant retina regions influencing predictions, making SmartEye an efficient and scalable solution for early refractive error screening and tele-ophthalmology applications.

Keywords: Myopia, Hyperopia, Fundus Images, Self-Supervised Learning, Vision Transformer, Ophthalmology, Deep Learning

1. Introduction

Refractive errors, including myopia and hyperopia, affect individuals across all age groups, with nearly half of the world's population projected to become myopic by 2050[1]. Conventional diagnostic procedures such as retinoscopy and autorefractors require skilled ophthalmologists and specialized equipment—resources that are limited in rural and underserved regions[2]. Despite advancements in AI and deep learning, several challenges persist: many existing models rely heavily on large annotated datasets, which are difficult and costly to obtain in medical imaging[4],[5]. Prior research has primarily focused on retinal diseases such as diabetic retinopathy, glaucoma, and AMD[6], while hyperopia remains underexplored due to subtle retinal manifestations[10].

Motivated by these gaps, this work explores self-supervised learning (SSL) for refractive error detection from fundus images. SSL enables models to learn meaningful visual representations from unlabeled data, reducing dependency on large labeled datasets while improving robustness across imaging variations[8]. By integrating SSL and Vision Transformer architectures, SmartEye aims to deliver improved diagnostic performance while remaining practical for large-scale screening and tele-ophthalmology applications[9].

Main Objectives:

- Develop a self-supervised learning framework for classifying normal, myopic, and hypermetropic cases from fundus images
- Reduce dependence on expert-annotated datasets through contrastive SSL feature learning
- Integrate a Vision Transformer classifier for enhanced global feature representation
- Evaluate the model across multiple public datasets and interpret predictions using Grad-CAM visualization

2. Literature Review and Methodology

The application of AI in ophthalmology has gained significant traction, particularly in fundus image analysis for automated disease detection[1],[2]. Self-supervised learning has emerged as a promising paradigm, allowing models to learn robust representations from unlabeled data[7]. Truong et al. proposed a self-supervised approach that reduced reliance on annotated datasets while achieving high accuracy in detecting multiple retinal disorders[8]. Recent research has explored AI for predicting refractive errors directly from retinal images, with CNN-based models estimating refractive error classification from fundus photographs[10]. However, these approaches typically rely on fully supervised learning and large annotated datasets, limiting their scalability in real-world settings[1].

Proposed SmartEye Framework: SmartEye consists of five major stages: (1) fundus image acquisition from datasets such as EyePACS, Messidor, and APTOS; (2) preprocessing including resizing, denoising, and contrast enhancement; (3) self-supervised feature extraction using contrastive learning; (4) classification using a lightweight Vision Transformer head; and (5) diagnosis output with Grad-CAM interpretability.

Core Architecture: The backbone consists of a ResNet-50 or Vision Transformer (ViT) base model. During SSL pretraining, augmented versions of the same image (rotations, cropping, color jitter) are used to learn invariant features[8],[9]. A projection head maps learned features into a latent space where contrastive loss is applied. After SSL pretraining, the projection head is discarded and a classification head is attached for fine-tuning on labeled data to classify images into normal, myopia, or hyperopia[4],[6].

3. Experimental Results and Analysis

SmartEye is evaluated using EyePACS, Messidor, and APTOS datasets. All images are resized to 224×224 pixels with preprocessing steps including Gaussian filtering for denoising, histogram equalization for contrast enhancement, and color normalization[5]. Standard data augmentations such as random cropping, rotations, and color jitter are applied during training[8].

Model	**Accuracy**	**Precision**	**Recall**	**F1-Score**
Baseline CNN	0.85	0.84	0.83	0.83
SmartEye (SSL+ViT)	0.91	0.90	0.91	0.90

Table 1: Performance Comparison: Baseline CNN vs. SmartEye

The results demonstrate that the SSL approach achieves superior performance across all metrics[8]. SmartEye outperforms the baseline CNN model by 6% in overall accuracy with improvements in precision, recall, and F1-score. The system demonstrates improved discrimination between myopia and hyperopia compared to the baseline model[2], with particularly strong performance in myopia detection while maintaining competitive accuracy for hyperopia cases.

6 Grad-CAM visualizations highlight retinal regions influencing the model's decisions, with patterns qualitatively aligning with expert expectations. Compared to prior deep learning approaches for fundus-based screening, SmartEye achieves higher or comparable accuracy while requiring fewer labeled samples due to self-supervised pretraining[9].

4. Discussion and Applications

Key Strengths: SmartEye significantly reduces dependence on large expert-annotated fundus datasets through SSL[1],[8],[9]. The system achieves high diagnostic accuracy with limited labeled samples by leveraging large volumes of unlabeled fundus images, learning robust representations that generalize well to clinical data[9]. The lightweight architecture enables deployment in resource-constrained environments such as rural health centers and telemedicine platforms[1]. Grad-CAM visualizations enhance clinical trust by clearly indicating which retinal regions influence diagnostic decisions[7].

Clinical Applications: In rural healthcare settings with limited ophthalmologist availability, SmartEye provides automated refractive error screening[10]. The system can be deployed in school screening programs for large-scale detection in school-age children, telemedicine platforms for remote diagnosis and referral through cloud-based integration, and elderly population screening for early detection of age-related hyperopia.

Future Directions: Expanding datasets to include more balanced hyperopia cases, extending diagnostic capabilities to include refractive error severity and prescription prediction, integrating multimodal imaging (OCT scans with fundus images), deploying in real-world telemedicine platforms, validating across diverse demographic populations, and developing mobile-compatible versions for smartphone-based fundus imaging devices.

5. Conclusion

Refractive errors represent a growing global health challenge, with traditional diagnostic methods limited by dependence on trained ophthalmologists and specialized equipment. This work introduced SmartEye, a self-supervised AI system for automated refractive error detection using fundus images. The proposed system integrates preprocessing, self-supervised feature learning, and lightweight classification to achieve
5 high diagnostic accuracy while reducing reliance on large annotated datasets. Experimental evaluation demonstrated that SmartEye outperforms baseline approaches, achieving over 90% accuracy with interpretability features enhancing clinical trust. By bridging the gap between limited clinical resources and increasing demand for vision screening, SmartEye provides a pathway toward reducing the burden of uncorrected refractive errors worldwide.

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