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DetectDiab: Observation of Diabetic Retinopathy Progression Based on Deep Learning Object Detection Using a Web Application with Client-Side Processing

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Abstract

Diabetic retinopathy is a serious complication of diabetes that affects the retinal tissue and can cause oxygen deficiency, abnormal blood vessel growth in the eye, and severe visual impairment or even blindness. Limited access to healthcare services in rural and remote areas in Indonesia affects this condition, as it is difficult for people to get regular eye examinations. On the other hand, the increasing use of biometric data in digital services requires serious attention to security and privacy aspects, given that people's biometric data is very important to protect. Therefore, this study aims to develop an AI-based application that can recognize the severity of diabetic retinopathy from retinal images uploaded by users online or offline (without a network). Since this study uses Client-Side Processing, fundus photos will not be uploaded to any server to protect users' personal data. The application was created by collecting retinal data from the APTOS 2019 Blindness Detection public dataset, followed by AI training using Edge Impulse with the Bring Your Own Mode (BYOM) method. The AI training results were launched on the Detectdiab website application. It was then tested and validated by ophthalmologists, medical personnel, and other volunteers. This research has successfully developed DetectDiab, a prototype website application that functions for early detection and observation of the progression of diabetic retinopathy. This application was built using the MobileNetV2 deep learning model with the highest accuracy of 78% compared to other models. However, optimization is still needed in the mild class to achieve higher accuracy. Client-Side Processing technology using TensorFlow WebAssembly (WASM) enables retinal image analysis to be performed entirely on the user's device, ensuring data privacy and security.

Keywords: Diabetic Retinopathy, Client-Side Processing, Artificial Intelligence, Deep Learning

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1. Introduction

1.1 Background

Diabetes mellitus is a metabolic disease characterized by hyperglycemia and disturbances in carbohydrate, fat, and protein metabolism due to an absolute or relative deficiency in insulin secretion or action. This disease is often referred to as a silent killer because it can affect multiple organs and cause serious complications, such as visual impairment, heart disease, kidney disorders, stroke, and vascular abnormalities (Zehirum et al., 2024). One of the most high-risk complications is diabetic retinopathy (DR), which is damage to retinal tissue caused by prolonged high blood glucose levels. This condition leads to blockage of retinal blood vessels, reducing blood flow and oxygen supply, which subsequently triggers the growth of abnormal blood vessels at advanced stages. These vessels are fragile and prone to rupture, potentially causing hemorrhage, scarring, and even retinal detachment. Without proper treatment and early detection, diabetic retinopathy can progress and result in severe visual impairment or blindness (Akhtar et al., 2025).

On the other hand, the utilization of retinal images in digital technology introduces new challenges related to data security and privacy. The viral case of retinal scanning by the Worldcoin service highlights that biometric data are highly sensitive and vulnerable to misuse if not managed securely, as biometric data breaches can have long-term consequences for individual identity and privacy. Therefore, the development of health detection systems based on retinal images must seriously consider data security aspects so that technological benefits do not create new risks for society (Quamila, 2025).

Limited access to healthcare services in rural and remote areas of Indonesia remains a major challenge that directly impacts the quality of life of communities. Geographic factors such as long distances to healthcare facilities and poor transportation infrastructure make it difficult for people to obtain timely medical care. This situation is exacerbated by shortages of professional medical personnel and inadequate healthcare facilities in these regions (Putri & Rachmawati, 2023). As a result, chronic diseases such as diabetic retinopathy are often undiagnosed or untreated, leading to serious complications, including blindness. Beyond physical impacts, limited access also affects social and economic aspects, such as reduced productivity, increased poverty rates, and widening social inequality (Yuliana et al., 2022). Therefore, communities require solutions to address these issues, such as assistive tools or web-based applications that can support people in remote rural areas. In this context, the development of applications such as DetectDiab can be highly beneficial.

An object detection approach using deep learning through a client-side web-based application is chosen because it is more practical, fast, and capable of directly displaying detected areas on retinal images. In addition, client-side processing helps maintain user data privacy and reduces dependence on servers. This study develops a prototype system for detecting the progression of diabetic retinopathy based on retinal modeling, called DetectDiab. DetectDiab is designed to identify progressive changes in the retina through the application of deep learning–based object detection technology. The system is built as a web application using a client-side processing approach, enabling real-time diabetic retinopathy detection without

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transmitting data to a server, thereby preserving user privacy. This prototype aims to provide a fast, accurate, and secure early detection solution for patients, while supporting efforts to prevent blindness caused by diabetic retinopathy.

1.2 Problem Formulation

Based on the background described above, the research problems are formulated as follows:

1. How can DetectDiab be developed to assist in the early detection of diabetic retinopathy using retinal images and Artificial Intelligence technology?
2. Can DetectDiab provide fast and user-friendly classification results through a web-based application?

1.3 Research Objectives

The objectives of this study are:

1. To create an Artificial Intelligence-based model that can recognize the severity of diabetic retinopathy from retinal images.
2. To evaluate the effectiveness of website applications in displaying retinopathy classification results based on images uploaded by users.

1.5 Benefits of Research

1.5.1. Theoretical Benefits

This research adds to the understanding of the use of Artificial Intelligence in the detection of diabetic retinopathy, as well as serving as a reference for the development of health technology and further research in similar fields.

1.5.2. Practical Benefits

The results of this research can be used by medical personnel to detect diabetic retinopathy more quickly and accurately, as well as assist policymakers in developing digital screening systems in healthcare services.

2. Literature Review

2.1 Diabetic Retinopathy

2.1.1 Definition and Epidemiology

Diabetic retinopathy (DR) is the leading eye complication of diabetes, affecting more than 100 million people globally. This disease causes damage to the blood vessels of the retina, which can lead to leakage, bleeding, and scar tissue formation (Tan & Wong, 2023). In addition, RD can also be characterized by changes in intraretinal vascularization that can cause blindness.

Diabetes mellitus causes chronic hyperglycemia, which triggers oxidative stress and inflammation, thereby damaging the endothelial cells of the retinal blood vessels (Tan & Wong, 2023; Elvira, 2019). The main mechanisms include activation of the polyol pathway

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and the formation of advanced glycation end products (AGEs), which accelerate retinal cell damage and worsen microvascular disorders (Elvira, 2019).

The result of this process is plasma leakage, microaneurysm formation, and hemorrhage, which are characteristic features of non-proliferative diabetic retinopathy. If this condition persists, retinal ischemia may occur, triggering neovascularization or the formation of abnormal new blood vessels, as seen in proliferative diabetic retinopathy, and further complications may include vitreous hemorrhage and retinal detachment (Tan & Wong, 2023).

2.1.2 Classification and Progression

Diabetic retinopathy (DR) is classified into non-proliferative diabetic retinopathy (NPDR) and proliferative diabetic retinopathy (PDR). Mild NPDR is characterized by microaneurysms as an early manifestation of vascular damage (Tan & Wong, 2018; American Academy of Ophthalmology, 2021). In the moderate stage, intraretinal hemorrhage, soft exudates, venous beading, and Intraretinal Microvascular Abnormalities (IRMA) appear (Elvira, 2019; Yang et al., 2022). Severe NPDR is characterized by extensive hemorrhage in all four quadrants, venous beading in two or more quadrants, and prominent IRMA (PERDAMI, 2018).

PDR is characterized by neovascularization, and in advanced stages, vitreous or pre-retinal hemorrhage may occur, as well as scar tissue formation that can cause retinal traction (Tan & Wong, 2018; PERDAMI, 2018; American Academy of Ophthalmology, 2021).

2.1.3 Current Diagnosis and Monitoring

Methods for diagnosing and monitoring Diabetic Retinopathy (DR) include funduscopy, fundus photography, Optical Coherence Tomography (OCT), and Fluorescein Angiography (FA). FA plays an important role in detecting abnormal retinal blood vessels (Purnama et al., 2023). Routine screening of people with diabetes is necessary to prevent the progression of DR and enable early intervention (Elvira, 2019).

2.2 Deep Learning Modeling

Deep Learning (DL) is a computational approach that uses multiple layers to extract features and learn data representations at a more abstract level (Nadeem et al., 2022). This technology demonstrates high performance in medical image analysis, including retinal imaging, with improved accuracy in screening, segmentation, and classification (Mohammed & Al-Ani, 2020; Viedma et al., 2022). Convolutional Neural Network (CNN) is the most commonly used model, superior to traditional methods, especially in segmenting retinal layers in OCT images (Viedma et al., 2022).

CNN-based object detection techniques will be used to identify eye structures and lesions in fundus images, such as cataracts and diabetic retinopathy, with an accuracy of 85%–98% (Ardyansyah & Gunawansyah, 2023; Amrullah & Irawan, 2023). This process generally uses image quality enhancement, such as histogram equalization or CLAHE (Contrast Limited Adaptive Histogram Equalization) (Amrullah & Irawan, 2023). In addition, the SVM method is also used with an accuracy of up to 82% for cataract classification (Munarto, 2019). However, models such as VGG-16 only achieve 45% accuracy in multi-eye disease

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classification, indicating challenges in developing more accurate and generalizable models (Qulub & Agustin, 2024).

2.3 Client Side Processing

Client Side Processing (CSP) in website application development is a computational process performed on the user's device to improve responsiveness and reduce server load (Elsen et al., 2023). CSP is usually implemented through JavaScript or Website Assembly, which allows pre-compiled binary files to be sent to clients for execution efficiency (Elsen et al., 2023). This approach is widely used in Single Page Applications (SPAs), which enable interaction without the need to reload pages (Belluano, 2018). CSP also supports real-time data management and accelerates information exchange, thereby saving software resources (Belluano, 2018). However, choosing between CSP and Server Side Rendering (SSR) requires consideration of the impact on site performance, such as loading speed and file size (Ardiyanto & Ardhianto, 2024). CSP development can also be done using frameworks such as Laravel, although this framework is by default more server-side oriented (Tiawan & Afuan, 2020).

3. Conclusions

Based on the results of the research and discussion outlined in the previous chapter, it can be concluded that this study successfully developed DetectDiab, a prototype website application designed for the early detection and monitoring of diabetic retinopathy progression. The application was built using the MobileNetV2 deep learning model combined with client-side processing through TensorFlow Website Assembly (WASM), enabling retinal image analysis to be conducted entirely on the user's device, thereby enhancing data privacy and security. The artificial intelligence (AI) model achieved an overall accuracy of 78%, performing exceptionally well in identifying retinas without abnormalities (NoDR) with a recall rate of 97.2%, and demonstrating reasonable reliability in detecting moderate retinopathy. However, the model still faces limitations in accurately distinguishing between mild, severe, and proliferative stages, as reflected in the lower recall values for these categories.

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