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DIABETIC RETINOPATHY SEVERITY GRADING USING IMAGE CONTENT

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1. Introduction

Diabetic retinopathy is a neurovascular condition that occurs in individuals with Type 1 and Type 2 diabetes. The likelihood of experiencing this consequence is strongly associated with the duration of symptoms and the effectiveness of glycemic management. According to a global meta-analysis, approximately 35.4% of individuals with diabetes experience retinopathy, with 7.5% of them having the proliferative type of this problem [6]. Diabetic retinopathy, as its name implies, can adversely affect vision and is currently recognised as the primary cause of new instances of blindness in adults living in developed nations. It typically manifests at an earlier stage and with greater frequency compared to other ocular problems in individuals with diabetes.

Research has demonstrated that actively controlling diabetes with the goal of achieving near-normal blood sugar levels can effectively slow down the advancement of diabetic retinopathy and potentially even prevent the development of diabetes [7,8]. Lowering blood pressure is advantageous in slowing down the progression of retinopathy in individuals with type 2 diabetes. However, there is no extra advantage in achieving systolic objectives below 140 mmHg [8,9]. Furthermore, fenofibrate supplementation has been investigated in trials such as the ACCORD Eye Study and FIELD, demonstrating possible therapeutic efficacy in decreasing the likelihood of diabetic retinopathy advancement.

Regarding the beginning of the condition, retinopathy that poses a risk to eyesight rarely happens within the initial 3-5 years of type 1 diabetes or before to reaching puberty [10]. It is advisable to undergo routine eye exams, performed by an ophthalmologist or optometrist, within five years of being diagnosed with type 1 diabetes, in order to promptly identify any potential issues. By contrast, a significant proportion of individuals diagnosed with type 2 diabetes, approximately 20%, already exhibit retinopathic problems, making it imperative to do early eye examinations at the time of diagnosis to promptly address the issue. Following assessments, typically conducted on a yearly basis for individuals with minor retinopathy, it may be appropriate to switch to a cost-efficient plan every two years, depending on normal results. However, a more regular schedule is necessary if retinopathy is progressing.

Pregnancy heightens the likelihood of expedited retinopathic development in both forms of diabetes [11]. Although it is not mandatory for women with gestational diabetes mellitus to have eye examinations, it is recommended that women with pre-existing diabetes undergo a pre-pregnancy ocular examination. It is recommended to have regular eye exams throughout pregnancy, particularly in the first trimester, and more frequent follow-ups may be necessary depending on the severity of symptoms [12].

Research has demonstrated that consistent monitoring, early detection, and treatment can effectively prevent up to 98% of vision loss in cases of diabetic retinopathy [13]. It is ideal for these tests to be carried out by skilled and experienced ophthalmologists or optometrists, who should promptly refer patients with diabetic retinopathy. Utilising remote analysis of high-resolution retinal images by specialists can improve the effectiveness of screening, particularly in regions with limited access to eye care providers. Nevertheless, it is important to emphasise that retinal pictures cannot replace thorough eye examinations, which should be conducted initially and at regular intervals as advised. It is essential to record and convey all examination results to the healthcare provider who made the referral in order to ensure thorough patient care.

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Diabetic retinopathy is a multifaceted eye disorder that occurs due to harm to the blood vessels in the retina [2,14]. The retina is a light-sensitive tissue located in the eye that is crucial for converting light into nerve impulses, so enabling the transmission of visual information to the brain. Nevertheless, when influenced by the consequences of diabetes, the intricate vascular network within the retina experiences alterations that might hinder vision.
Diabetic retinopathy causes vision loss through multiple processes. Macular edoema, resulting from heightened permeability of the blood vessels, might potentially hinder central vision. This condition may or may not be accompanied by nonperfusion of the capillaries. As a result, the growth of new blood vessels in proliferative diabetic retinopathy and the shrinking of the connected fibrous tissue can cause the retina to become distorted. This distortion can lead to tractional retinal detachment, which can cause significant and usually permanent visual loss. Another difficulty develops when these newly formed blood vessels experience bleeding, which further complicates the situation with retinal or vitreous haemorrhage. The visible alterations in the blood vessels align with the breakdown of neurons in the retina, which is considered the most likely pathogenic change responsible for vision loss [15].
Over the years, there have been significant advancements in diagnostic assessment, such as the utilisation of Optical Coherence Tomography (OCT) to precisely measure the thickness of the retina and, consequently, detect retinopathy. Clinicians have also utilised wide-field fundus photography to reveal previously unidentified abnormalities in the microvasculature. The American Diabetes Association [16] categorises the advancement of the disease into four stages based on their level of severity.
Stage 1 of diabetic retinopathy is characterised by moderate, non-progressive symptoms. At this early stage, microscopic balloon-like swellings called microaneurysms develop in the tiny blood vessels of the retina. These microaneurysms have the potential to release fluid into the retina.
Stage 2 of diabetic retinopathy is characterised by moderate non-progressive changes in the blood vessels that supply nutrients to the retina, resulting in swelling and distortion. Additionally, they may experience a loss in their capacity to circulate blood. Both diseases result in distinct alterations to the retina's visual aspect and may potentially lead to the development of diabetic macular edoema.
Stage 3 is characterised by advanced non-progressive diabetic retinopathy, in which a greater number of blood vessels get obstructed, leading to a lack of blood supply in certain parts of the retina. These regions release growth factors that communicate to the retina to generate new blood vessels. • Stage 4 is characterised by advancing diabetic retinopathy, in which growth factors released by the retina stimulate the formation of new blood vessels. These vessels develop along the inner surface of the retina and extend into the vitreous gel, the fluid within the eye. The newly formed blood vessels exhibit fragility, rendering them prone to leakage and haemorrhage. Scar tissue that accompanies can constrict and result in retinal detachment, where the retina is pulled away from the underlying tissue, similar to how wallpaper peels away from a wall. Retinal detachment may result in irreversible vision impairment.
Diabetic retinopathy has a diverse range of effects on vision, varying from slight blurring to total loss of eyesight [17]. This ailment exhibits itself in many stages, each of which poses unique obstacles to the health of one's vision. Gaining a comprehensive understanding of these subtle distinctions is crucial for formulating precise interventions and proactive measures.
The retina serves as the primary entrance to the visual system, where it receives and processes light signals that are fundamental to visual experience. The occurrence of diabetic retinopathy, which is a disruption in the functioning of the eyes, can significantly impact an individual's visual perception of the environment [14,17]. The importance of the retina is crucial, emphasising the need to protect its well-being and swiftly resolve any issues.

(i) The eyes, especially the retina, are highly susceptible to changes caused by diabetes because of intricate physiological processes inherent in the small blood vessels and nerve cells of the visual system [18]. The complex network of tiny blood vessels in the retina, which is vital for delivering necessary oxygen and nutrients, is affected by the widespread harm typically linked to diabetes. Vascular impairment plays a crucial role in the onset of diabetic retinopathy.
(ii) Ocular susceptibility is closely related to the disruption of the blood-brain barrier (BBB), which is a protective barrier that safeguards the neural tissues of the retina. Diabetes has systemic effects that disturb the blood-brain barrier (BBB), which permits the entry of detrimental substances into the retinal environment and contributes to pathological alterations.
(iii) The neuronal components of the retina, specifically the light-sensitive cells known as photoreceptors, are especially susceptible to the metabolic disturbances associated with diabetes. This increased sensitivity leads to functional disruptions and progressive visual deterioration.
(iv) Diabetes causes a continuous, mild inflammation that affects the eye, making the Blood-Retinal Barrier (BRB) weaker and speeding up the development of diabetic retinopathy.
(v) Moreover, the development and buildup of advanced glycation end products (AGEs), which occur as a result of persistent elevated levels of glucose in the bloodstream, serve as an additional causative element. Advanced glycation end products (AGEs), which are commonly found in ocular tissues, contribute to the increased susceptibility of ocular structures to diabetes-induced alterations [19].
(vi) At the same time, the macula, which is an important area for central vision in the retina, becomes prone to excessive fluid buildup in people with diabetes, resulting in diabetic macular edoema. Failure to receive treatment for this illness presents a substantial threat to the clarity of central vision [14].

2. Literature Review

Diabetic retinopathy is a specific neurovascular problem that can occur in individuals with both type 1 and type 2 diabetes. The likelihood of developing this condition is closely linked to how long a person has had diabetes and how well their blood sugar levels are controlled. A global meta-analysis was undertaken from 1980 to 2008, involving 35 research. The analysis found that the prevalence of any diabetic retinopathy worldwide was 35.4%, while the prevalence of proliferative diabetic retinopathy among patients was 7.5% [6]. Diabetic retinopathy is the primary cause of new cases of blindness among persons aged 20 to 74 years in developed countries. Additional triggering issues in diabetics include cataracts, glaucoma, and other eye illnesses.
The worldwide prevalence of sight-threatening diabetic retinopathy in adults with diabetes is currently estimated to be 10.2% [1]. Diabetic retinopathy usually develops 4 to 7 years from the start of noninsulin-dependent diabetes mellitus [3]. Several pathogenic factors, including as the specific kind and duration of diabetes mellitus, blood pressure condition, and serum lipids, can impact the occurrence of diabetic retinopathy. Therefore, it is advisable for individuals with diabetes to receive a thorough examination of the eye, including an assessment of the dilated fundus. However, due to the scarcity of proficient ophthalmologists and optometrists, it is not feasible to conduct examinations on every individual with diabetes mellitus just from an ophthalmologist's perspective [4]. Hence, the significance of telemedicine becomes evident in the realm of diabetes, where essential physiological data and images of the fundus are gathered in close proximity to the patients' whereabouts. Afterwards, a geographically distant specialist in eye diseases evaluates the data to offer judgements on the existence or nonexistence of retinopathy and the need for medical intervention [20]. Based on the results of 6399 observational studies, it has been determined that diabetic retinopathy impacts approximately one-third of patients diagnosed with type 2 diabetes and

its prevalence increases with age [21]. The impacts of disease severity are experienced by 13.1% of newly diagnosed individuals [22].

Countries throughout the world have aligned their national priorities with the United Nations 2030 Sustainable Development Goals (SDGs) in order to work towards implementing the SDGs. Nevertheless, there is a distinct lack of satisfactory performance, specifically in low- and middle-income nations, in the realm of health and well-being (SDG 3). The lack of satisfactory performance in this area has a ripple effect on the advancement of the economy (SDG 8), education (SDG 4), and gender equality (SDG 5) [23]. The UK Government created the Global Challenges Research Fund in 2015 as a response to these difficulties. Implemented by delivery partners such as the United Kingdom Research and Innovation, this initiative seeks to tackle intricate global development challenges and foster cooperative research to improve economic well-being, welfare, and quality of life in countries with low and intermediate incomes.

An exemplary instance of such cooperative endeavours is the ORNATE India project, which receives backing from the Global Challenges Research Fund and United Kingdom Research and Innovation. This joint research endeavour between the United Kingdom and India aims to enhance research capacity and competency in both nations to tackle the prevalence of visual impairment caused by diabetes [24].

The main factors leading to visual impairment caused by diabetic retinopathy, a condition that endangers eyesight, are diabetic macular edoema and problems resulting from proliferative diabetic retinopathy. While both illnesses can be treated, individuals may not show symptoms for a long time until they have a significant deterioration in eyesight from moderate to severe. Hence, it is important to carry out screenings utilising retinal cameras or examinations performed by skilled ophthalmologists or optometrists to guarantee prompt detection, referral, and treatment, finally averting vision impairment.

Aside from encountering obstacles such as a greater prevalence of diseases, restricted resources, and an insufficiently skilled staff, there is an urgent requirement to formulate management protocols that are precisely tailored to the local requirements and available resources. The objective of this method is to establish a uniform standard of care for diabetic retinopathy in countries with low- and middle-income levels. It is crucial to handle the distinctive circumstances and ensure efficient management in these locations.

Low- and middle-income countries face constraints in acquiring expensive conventional retinal cameras, unlike high-income ones. Moreover, laser photocoagulation continues to be the predominant therapeutic approach for both diabetic macular edoema and proliferative diabetic retinopathy in these nations. The high cost of repeated intravitreal injections of anti-vascular endothelial growth factor medicines for diabetic macular edoema is the reason for their prohibitive expense. In addition, laser devices are expensive, and a considerable proportion of the population in low- and middle-income nations does not have access to these therapies. Managing the intricate problems of proliferative diabetic retinopathy requires the expertise of highly competent vitreo-retinal surgeons. However, the lack of adequate infrastructure in low- and middle-income countries sometimes hinders access to such specialised care [24].

Diabetic retinopathy, which is a consequence of diabetes mellitus affecting small blood vessels in the eyes, presents a significant risk to vision and overall eye health. With the global prevalence of diabetes reaching epidemic levels, diabetic retinopathy has become a prominent issue of public health importance. The development of diabetic retinopathy is sophisticated, requiring complex interactions across metabolic, vascular, and inflammatory processes. A comprehensive understanding is required to design effective prevention strategies and interventions due to its complex character [25].

Conducting research on diabetic retinopathy is of utmost importance due to multiple reasons. To begin with, the high frequency of diabetes necessitates a proactive strategy to tackle its ocular consequences. The prevalence of diabetes among adults is significantly higher in low- and middle-income countries, where the primary healthcare system is still in the process of being established. This poses a greater challenge in effectively managing diabetes and its associated sequelae, such as diabetic retinopathy [27]. Furthermore, diabetic retinopathy advances through distinct stages, ranging from mild non-proliferative forms to severe proliferative forms, each associated with varying risks of vision loss. Timely identification and intervention at the appropriate phase are crucial in averting lasting harm. The research is centred around finding reliable screening methods and creating precise classification algorithms to guarantee prompt and specific interventions. Furthermore, diabetic retinopathy has wide-ranging consequences that extend beyond the field of ophthalmology. The impact of vision impairment extends to economic growth, since it can impede workforce productivity. It also affects broader healthcare systems that are already struggling with the growing load of complications associated to diabetes. The importance of effective preventative strategies for diabetic retinopathy is underscored by the economic and societal consequences it entails [28].
The current research on diabetic retinopathy serves as the foundation of our comprehension of this ailment. The importance of these investigations resides not only in elucidating the complex pathophysiology of diabetic retinopathy but also in influencing clinical practices and public health policy. Groundbreaking research has identified risk factors linked to the development and advancement of diabetic retinopathy. These factors comprise chronic high blood sugar levels, kidney disease, high blood pressure, and abnormal lipid levels. The identification of these risk factors has facilitated the implementation of focused screening and intervention approaches, hence aiding in the prevention and management of diabetic retinopathy [26].
The development of imaging technologies, such as fundus photography and optical coherence tomography, has enabled accurate recording of retinal alterations linked to diabetes. The aforementioned investigations have played a crucial role in the development of dependable diagnostic criteria and monitoring tools [25]. Furthermore, many epidemiological research have yielded valuable information regarding the frequency and occurrence of diabetic retinopathy across various populations, which has been important in developing healthcare policies tailored to certain regions [22].
The incorporation of artificial intelligence and machine learning into diabetic retinopathy research has expanded the boundaries of investigation. Automated screening algorithms and image analysis techniques improve the effectiveness and precision of diagnosing diabetic retinopathy. These technology breakthroughs have the potential to completely transform large-scale screening programs, especially in areas with limited resources [26]. The extant research on diabetic retinopathy is crucial in shaping our comprehension of this intricate ailment. Their efforts have facilitated the development of cutting-edge diagnostic and therapeutic methods, advancing our progress towards the objective of averting eyesight impairment in patients suffering from diabetes. In the following chapters, we will explore the segmentation procedures, classification methods, and screening frameworks that serve as the basis for current and future developments in diabetic retinopathy research.
In the transition from the introductory overview to the examination of specific segmentation algorithms in diabetic retinopathy, we will now focus on the Taurus Wavelet Algorithm, which is a prominent method used for analyzing retinal images. This section thoroughly analyzes its goals, approach, and importance, utilizing insights from notable research, like the study conducted by Castro et al. [28]. This exploration seeks to elucidate the algorithm's effectiveness and conduct a comparative analysis with established benchmarks such as Digital Retinal Images for Vessel Extraction (DRIVE2) and Diabetic Retinopathy Database and Evaluation Protocol (DIARETDB03).

Additionally, it aims to critically evaluate the algorithm's strengths and potential limitations in its contribution to diabetic retinopathy studies.

3. Findings

The model we propose is built using the MATLAB programming language. The data will be split into three sets: 70% for training, 20% for validation, and 10% for testing. The Adam optimizer will be used with a batch size of 32 and a learning rate of 0.0001. The evaluation criterion used to assess the diagnostic performance of our proposed WFDLN consisted of four metrics: accuracy (ACC), sensitivity (SEN), precision (PRE), and specificity (SPE).

We conducted empirical research to assess the impact of our proposed weighted fusion method on the identification performance, specifically in terms of accuracy, using two benchmark datasets. The initial study exclusively focused on utilizing CLAHE fundus pictures to detect diabetic retinopathy (DR), while the subsequent study solely utilized CECED fundus images for DR detection. The integration of the suggested framework, as depicted in Figure 1, demonstrated that combining the CLAHE and CECED image features effectively addresses the issue of low-quality photos in DR identification. This approach resulted in improved accuracy in recognizing DR on both the Messidor and Kaggle datasets. Figure 1(a) depicts the accuracy training and validation curves of the proposed methodology on both datasets, demonstrating the smooth convergence of the model with high accuracy. Figure 1(b) illustrates the training and validation loss curves on both datasets, indicating that our model consistently reduces its loss.

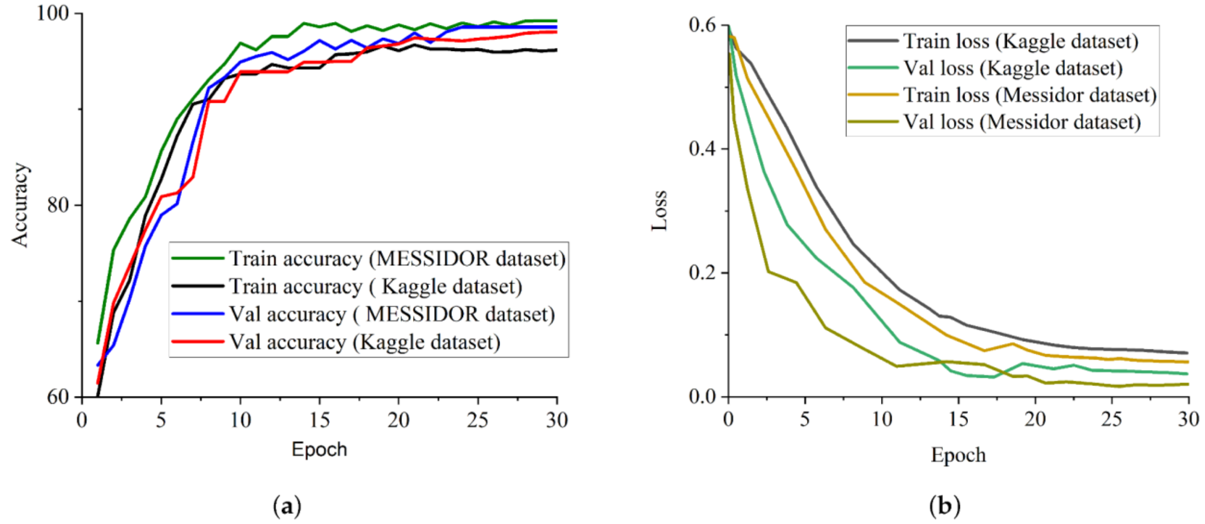

Figure 1. Report on the performance of our proposed model in training and validation using both the Messidor and Kaggle datasets. (a) Graph depicting the accuracy of our proposed model on both the Kaggle and Messidor datasets. (b) Loss curve depicting the performance of our proposed model on both the Kaggle and Messidor datasets.

Figure 2 displays the classification accuracy of both individual channels and the proposed weighted fusion deep learning network (WFDLN). The blue bar represents the CLAHE-based channel using an Inception V3 network for DR identification. The yellow bar shows the proposed WFDLN for DR identification. The green bar represents the CECED-based channel using the VGG-16 network for DR identification. Based on available evidence, the suggested model surpasses the single-based channels, attaining a 98.0% accuracy on the Kaggle dataset and a 98.5% accuracy on the Messidor dataset.

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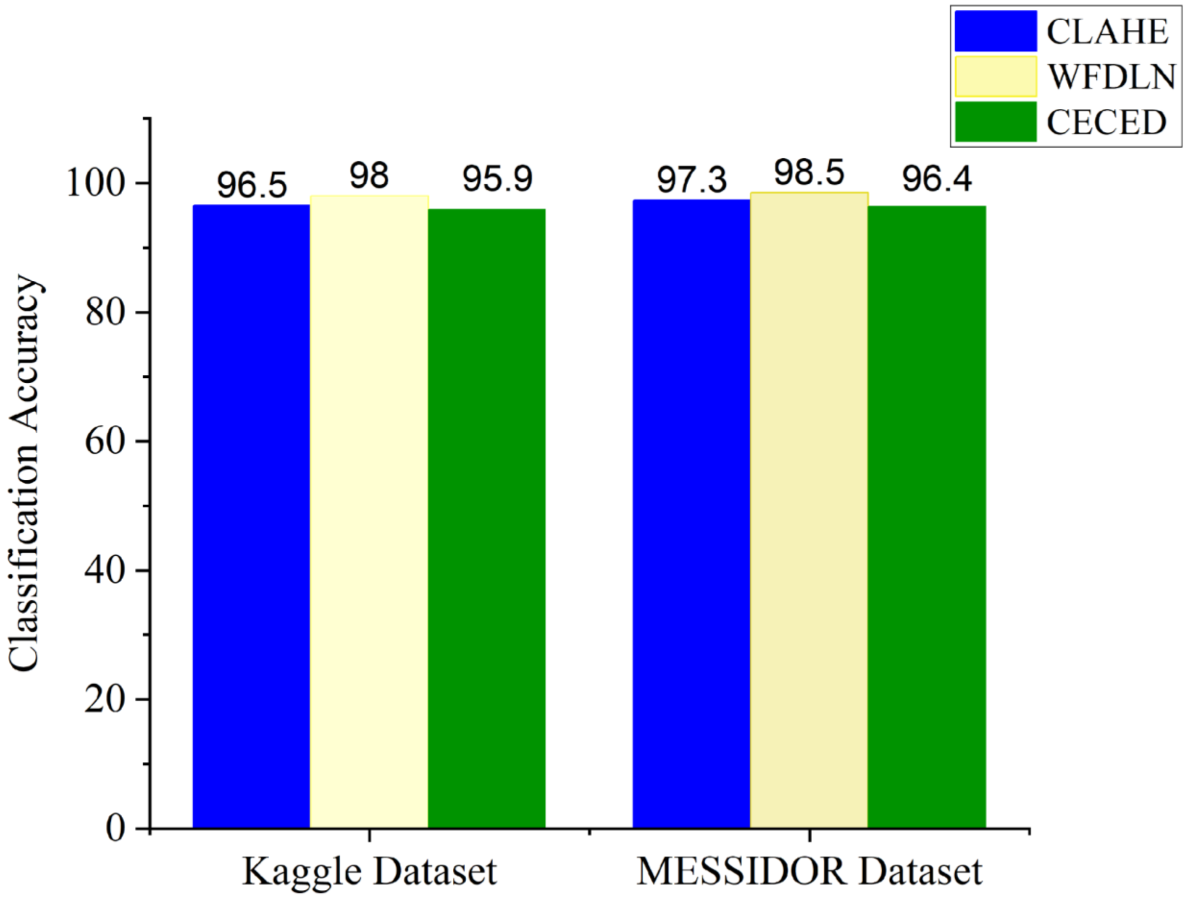

Figure 2. Accuracy of classification for individual channels and the proposed Weighted Fusion Deep Learning Network (WFDLN) model.

According to Figure 2, the CLAHE-based channel has a better accuracy level compared to the CECED-based channel. This indicates that CLAHE fundus images have a greater impact on identifying diabetic retinopathy (DR) than CECED fundus images. We conducted additional assessments of the proposed model's performance using metrics such as accuracy (ACC), specificity (SPE), sensitivity (SEN), and precision (PRE) on both datasets. These results are illustrated in Figure 3. The suggested model demonstrates superior performance on the Messidor dataset, reaching an accuracy of 98.5%, specificity of 98.0%, sensitivity of 98.9%, and precision of 99.2%, which may be empirically observed.

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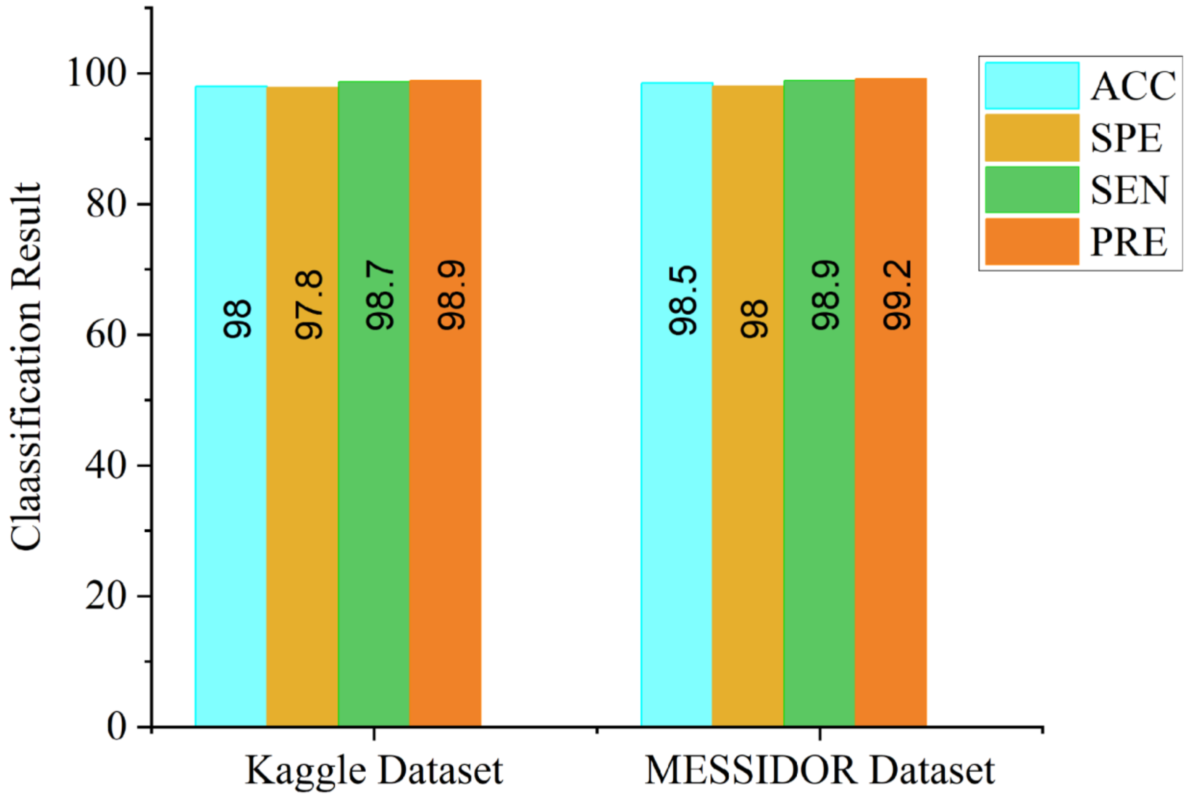

Figure 3. Our suggested model's classification results on the Kaggle and Messidor datasets.

Figure 4(a) displays the test accuracy curves of the proposed model compared to the single-based channels on the Messidor dataset. Figure 4(b) displays the test accuracy curves of the proposed model compared to the single-based channels on the Kaggle dataset. The superiority of the proposed model over the single-based channels is clearly apparent in both the Kaggle and Messidor datasets.

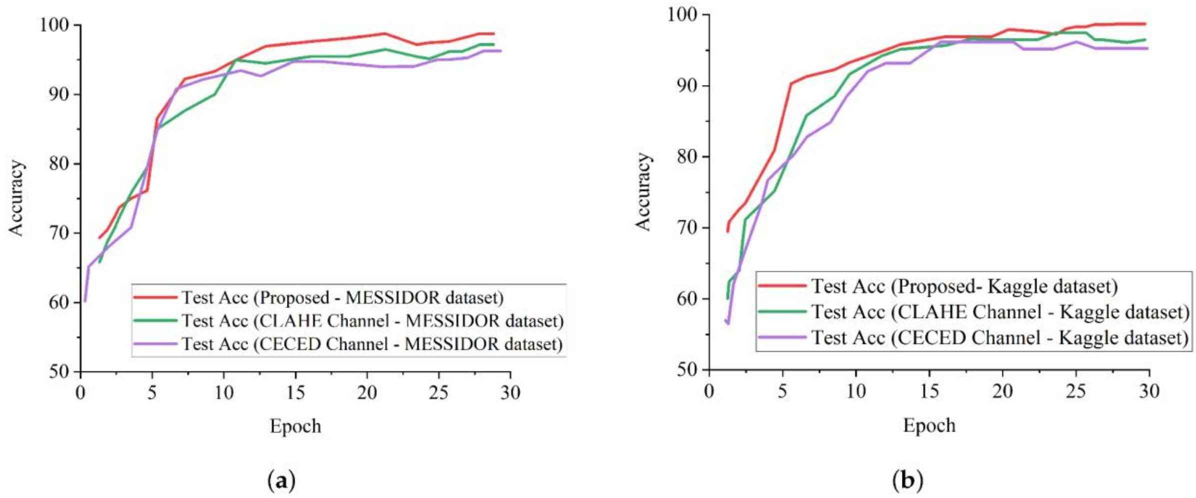

Figure 4. Report on the accuracy performance of our proposed model and single-channel models on both the Messidor and Kaggle datasets. (a) The test accuracy curve of our proposed model is compared with that of the single channels on the Messidor dataset. (b) Evaluate the precision of our proposed model by comparing its accuracy curve with that of the single channels on the Kaggle dataset.

4. Conclusion

To conclude, the complexities of how the eyes are affected by changes caused by diabetes entail the interaction of various elements, including the small blood vessels, nerves, inflammation, and metabolism. An intricate comprehension of these physiological underpinnings is crucial for understanding the progression of eye issues associated with diabetes and directing specific prevention and treatment approaches.

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