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Research Article

Detection of Diabetic Retinopathy Affected Regions Using Clustering Algorithms

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Abstract

Diabetes mellitus is a long-term metabolic condition that results in persistent high blood sugar and affects multiple organs over time. One of the most serious complications is diabetic retinopathy, a disorder in which the tiny blood vessels of the retina become damaged, leading to vision disturbances and, in severe cases, blindness. Since these changes in the retina often begin subtly, early identification of affected regions is essential for timely treatment and prevention of vision loss.

Methods: In this research, retinal images were first enhanced using a median filtering technique to suppress noise and improve visual clarity. The processed images were then segmented using two unsupervised clustering algorithms: K-Means and Fuzzy C-Means (FCM).

Findings: A comparative analysis was carried out to determine which method provides better results in highlighting diseased retinal regions. The outcomes indicated that K-Means produces faster segmentation with simpler boundaries, whereas FCM achieves more precise detection by identifying finer details such as microaneurysms and small vessel changes. From the comparison, it can be concluded that while K-Means may be suitable for quick image partitioning, FCM is more reliable for accurate medical diagnosis. This makes FCM a stronger tool for computer-aided detection of diabetic retinopathy in clinical settings.

Keywords: Diabetic Retinopathy, Retinal Fundus Images, Image Segmentation, K-Means Clustering, Fuzzy C-Means Clustering, Median Filtering, Medical Image Processing.

Introduction

Diabetes mellitus is one of the most common metabolic disorders worldwide, affecting millions of people across different age groups. Characterized by chronic hyperglycemia, diabetes gradually damages blood vessels and nerves, leading to complications that affect vital organs such as the heart, kidneys, and eyes. Among these complications, diabetic retinopathy has emerged as a significant public health concern. This eye disorder occurs when high blood sugar levels cause structural and functional changes in the retinal blood vessels, resulting in microaneurysms,

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hemorrhages, exudate, and, in advanced stages, the formation of abnormal new vessels. If left untreated, diabetic retinopathy can progress to partial or complete blindness, making it one of the leading causes of vision loss in adults worldwide [1].

The retina plays a critical role in vision, as it is responsible for capturing light and transmitting visual signals to the brain. When diabetes weakens or blocks the tiny vessels that nourish the retina, the affected regions begin to lose their ability to function normally. The early stages of diabetic retinopathy often go unnoticed because the changes are subtle and painless. This silent progression emphasizes the importance of regular screening and early identification of affected areas in the retina [1]. However, traditional diagnostic methods largely rely on manual evaluation by ophthalmologists, which can be time-consuming and subjective. With the rising global burden of diabetes, there is a growing demand for computer-aided diagnostic systems that can quickly and accurately detect retinal abnormalities. Medical image processing has gained increasing attention in recent years as a powerful tool for automated disease detection. Retinal fundus images, when enhanced and analyzed using digital techniques, can reveal hidden patterns and subtle variations that may not be easily observed by the human eye. One of the critical steps in this process is image segmentation, which involves dividing an image into meaningful regions to highlight affected areas of the retina. Segmentation allows clinicians and researchers to focus specifically on diseased regions while minimizing interference from normal structures. Among the various segmentation techniques, clustering-based algorithms such as K-Means and Fuzzy C-Means (FCM) are widely applied in medical image analysis. K-Means is a simple and efficient algorithm that partitions image pixels into predefined clusters based on similarity measures. Although computationally fast, K-Means assigns each pixel strictly to one cluster, which may result in the loss of finer details. On the other hand, FCM allows pixels to belong to multiple clusters with varying degrees of membership. This fuzzy approach enables more flexible and accurate segmentation, especially in cases where image boundaries are unclear or when retinal lesions have overlapping intensity values [3]. Applying clustering methods to retinal images provides a systematic way to identify regions affected by diabetic retinopathy. When combined with preprocessing techniques such as median filtering to reduce noise, these algorithms enhance the overall accuracy of disease detection. Comparative studies between K-Means and FCM can provide valuable insights into which algorithm performs better in isolating abnormal retinal regions, thereby supporting the development of robust computer-aided diagnostic tools. In this study, an image processing approach is proposed for detecting diabetic retinopathy–affected regions using retinal fundus images. Median filtering is first applied to improve image clarity by removing noise. The filtered images are then segmented using both K-Means and FCM algorithms. A comparative analysis of the segmentation results is presented to evaluate their effectiveness in identifying retinal disease regions. The findings aim to contribute to improved automated screening methods for diabetic retinopathy, ultimately assisting ophthalmologists in providing early and reliable treatment for patients at risk of vision loss. In the study focus section 1 introduction, the 2nd section introduced related work, and section 3 focuses on methodology. The next section 4 discusses results. Finally, in the section conclusion.

Related Works

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Diabetes mellitus is one of the fastest-growing chronic diseases worldwide, and diabetic retinopathy (DR) is a leading cause of vision impairment among adults. Prolonged hyperglycemia damages the retinal blood vessels, leading to leakage, microaneurysms, and abnormal neovascularization. The silent progression of DR highlights the importance of early diagnosis and screening. According to the World Health Organization, nearly one-third of people with diabetes develop some form of retinopathy, making automated detection methods increasingly valuable [4].

Early identification of affected retinal regions relies heavily on image processing techniques. Traditionally, ophthalmologists detect DR through clinical examination and fundus photography. However, manual diagnosis is time-consuming and prone to human error, particularly when analyzing large populations. As a result, researchers have turned to computer-aided systems that utilize segmentation and clustering techniques to identify abnormal structures in retinal images [5].

Studies on diabetic retinopathy detection

Several studies emphasize the need for automatic DR detection systems. [5]. pioneered the use of neural networks for identifying early signs of retinopathy, demonstrating the potential of computer-based models to support medical screening (94). Building on this, Niemeijer et al. [6] proposed an automated system that classifies retinal vessels and lesions, reporting significant accuracy improvements over traditional approaches (189). These works collectively highlight the importance of automated analysis in detecting subtle abnormalities in retinal images.

Segmentation and Image Enhancement Techniques

Image preprocessing is a crucial step in retinal disease detection. Median filtering is often used to enhance images by reducing noise while preserving important structures such as vessels. According to Gargeya & Leng [7], median filtering is particularly effective in medical images where salt-and-pepper noise can obscure fine details in 221 images. Enhanced images serve as input for segmentation algorithms that divide the retina into meaningful regions. Segmentation methods are commonly grouped into thresholding, edge detection, and clustering approaches. Among these, clustering has emerged as a robust solution for retinal analysis. Clustering allows grouping of pixels based on intensity and similarity without requiring prior labeling. This is particularly beneficial for medical imaging, where ground truth annotations are often limited.

The K-Means clustering in retinal imaging

K-Means clustering is widely used for retaining image segmentation due to its simplicity and speed. Osareh et al [8]. applied K-Means to segment the optic disc and blood vessels, reporting accurate identification of structural regions critical for DR diagnosis. Similarly, Kavitha and Shenbaga Devi demonstrated that K-Means effectively separates normal tissue from affected regions, enabling early identification of lesions such as exudates. However, one limitation of K-Means is its sensitivity to noise and difficulty in handling overlapping clusters, which are common in retinal structures.

Fuzzy C-Means in medical segmentation

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To overcome the limitations of K-Means, researchers have explored Fuzzy C-Means (FCM) clustering. Unlike K-Means, which assigns each pixel to a single cluster, FCM allows partial membership, making it better suited for images with blurred boundaries. Chutatape and Zheng applied FCM to segment retinal blood vessels and reported higher accuracy in detecting fine vessel structures compared to K-Means. Furthermore, Selvathi et al [9]. demonstrated that FCM segmentation improves the detection of microaneurysms, a key indicator of DR progression. These findings suggest that FCM provides greater diagnostic reliability despite its higher computational cost.

Comparative studies

Several comparative studies have been conducted to evaluate clustering methods in retinal imaging. For instance, Pal and Bandyopadhyay compared K-Means and FCM for retinal segmentation and found that FCM produced more accurate boundaries, while K-Means was faster for large datasets. Similarly, Dash and Meher reported that FCM achieved better sensitivity and specificity in detecting affected regions of diabetic retinopathy. These studies confirm that while both methods are useful, FCM is generally superior for clinical applications requiring high accuracy. The reviewed literature indicates that diabetic retinopathy poses a major health burden, and automated image segmentation provides an effective tool for early detection. Median filtering improves preprocessing, while clustering algorithms such as K-Means and FCM are widely applied for retinal analysis. K-Means offers computational efficiency, but FCM delivers more precise segmentation, especially for detecting subtle abnormalities. Comparative studies consistently highlight the diagnostic advantages of FCM, making it a preferred choice for clinical decision support systems [6,8-10].

Methodology

Diabetes mellitus is one of the most common chronic illnesses affecting millions of individuals worldwide. Poorly managed diabetes often results in several complications, among which diabetic retinopathy (DR) is the most prevalent cause of vision loss. Retinal damage occurs when prolonged hyperglycemia weakens and damages the small blood vessels of the retina, leading to leakage, microaneurysms, hemorrhages, and, in severe cases, blindness. Early detection of retinal abnormalities is essential for preventing progression of the disease. However, manual screening by ophthalmologists is resource-intensive and prone to human error. Therefore, computer-aided diagnostic techniques have emerged as valuable tools for enhancing the accuracy and efficiency of retinal disease detection. This research focuses on using clustering-based image segmentation methods to identify disease-affected regions in retinal images of diabetic patients. The methodology integrates preprocessing and clustering algorithms to improve the visualization of abnormal retinal features. (Figure 1)

shows the research flow in given blocks.

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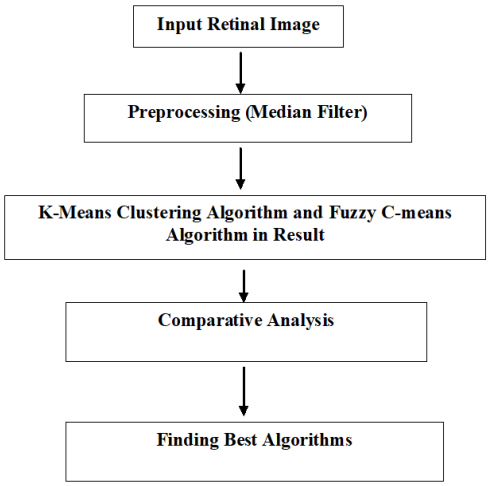


Figure 1. Shows the research flow diagrams.

Dataset description

Retinal fundus images used in this study were obtained from a private hospital located in Tamil Nadu, India. Ethical approval was secured before data collection, and informed consent was obtained from patients whose images were included in the dataset. The dataset consisted of anonymized digital fundus photographs, including both healthy and diseased retinas. These images represent a real-world clinical setting, enhancing the practical relevance of the study.

Preprocessing

Preprocessing was performed to enhance image quality and prepare the dataset for segmentation. A Median Filtering approach was applied to each image to reduce salt-and-pepper noise while preserving the edges of retinal blood vessels. This filtering step ensures that important retinal structures remain intact, thereby improving the accuracy of subsequent segmentation. Contrast adjustment and normalization were also carried out to improve the visibility of microaneurysms, hemorrhages, and other pathological features.

Segmentation techniques

The main objective of segmentation was to isolate affected regions in the retina. Two unsupervised clustering methods were applied: **K-Means Clustering**. This algorithm partitions the image into "k" clusters by minimizing intra-cluster variance. It is computationally efficient and provides faster results, making it suitable for large datasets. However, it may struggle with overlapping intensities and fine retinal details. **Fuzzy C-Means (FCM) Clustering**: Unlike K-Means, FCM allows pixels to belong to more than one cluster with varying degrees of membership. This property makes it more suitable for medical images, where boundaries between healthy and diseased regions are not always distinct. FCM was applied to detect subtle retinal abnormalities such as microaneurysms and small hemorrhages.

Clustering algorithms

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The K-Means clustering research steps:

In this study, K-Means clustering was employed as one of the primary algorithms for segmenting retinal images to detect diabetic retinopathy–affected regions. The algorithm was carried out in the following steps:

1. **Initialization:** A predefined number of clusters (k) was selected based on the retinal image characteristics. These clusters represent potential regions such as healthy tissues, lesions, and background.
2. **Centroid Selection:** The algorithm randomly selected k initial centroids within the image feature space. Each centroid acted as the representative point for its cluster.
3. **Pixel Assignment:** Every pixel in the retinal image was assigned to the nearest centroid by calculating the Euclidean distance. This step grouped pixels with similar intensity and color values into the same cluster.
4. **Centroid Update:** After assignment, the centroid of each cluster was recalculated as the mean of all pixel values within that cluster. This adjustment refined the cluster center to better represent the assigned pixels.
5. **Iteration:** The pixel assignment and centroid update steps were repeated until the centroids stabilized, meaning no significant changes occurred in cluster positions. This ensured convergence and consistency in segmentation results.
6. **Final Segmentation:** The clusters obtained at the end of the iterations represented distinct regions of the retina. Diseased areas such as microaneurysms, hemorrhages, and exudates were more clearly separated from the healthy regions.

Fuzzy C-Means (FCM) algorithm–research steps:

The Fuzzy C-Means (FCM) clustering algorithm was employed in this study to segment retinal images and identify regions affected by diabetic retinopathy. Unlike conventional hard clustering methods, FCM allows each data point (pixel) to belong to multiple clusters with different degrees of membership, making it more suitable for medical image analysis, where boundaries are often indistinct. The steps followed are outlined below:

1. **Initialization:** The number of clusters (c) was defined based on the image segmentation requirement. An initial fuzzy partition matrix was generated, assigning each pixel a random membership value between 0 and 1, ensuring that the sum of memberships for each pixel equaled 1.
2. **Centroid Calculation:** Cluster centroids were calculated by taking the weighted mean of all pixels, where the weights corresponded to the membership values. This ensured that pixels with higher memberships contributed more to centroid formation.
3. **Membership Update:** The membership values of each pixel were updated according to the distance between the pixel intensity and the cluster centroids. Pixels closer to a centroid received higher membership degrees, while distant pixels received lower values.
4. **Iteration Process:** Steps 2 and 3 were repeated iteratively. The process continued until the membership matrix stabilized, i.e., when the difference between successive iterations fell below a pre-defined threshold (convergence condition).

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5. **Segmentation Output:** Once convergence was achieved, each pixel was assigned to the cluster where it held the highest membership value. This final clustering provided a soft segmentation of the retinal image, distinguishing normal tissue from diabetic retinopathy–affected regions.
6. **Detection of Diseased Areas:** The final segmented output highlighted abnormal features such as microaneurysms, hemorrhages, and exudates. Since FCM permits partial membership, it proved effective in handling the overlapping intensity levels often present in retinal images, thereby providing more accurate detection compared to hard clustering approaches.

Evaluation and Comparison

The results of both clustering techniques were compared in terms of their ability to highlight disease-affected regions. Visual inspection by medical experts was used to validate segmentation accuracy. In addition, quantitative measures such as segmentation clarity, preservation of fine details, and computational efficiency were recorded. The methodology integrates real-world retinal images from a Tamil Nadu hospital, preprocessing through median filtering, and segmentation via K-Means and FCM algorithms. This stepwise approach ensures both computational efficiency and medical relevance, enabling an evidence-based comparison of clustering algorithms for diabetic retinopathy detection.

Result and Discussion

The analysis of retinal images collected from private hospitals in Tamil Nadu focused on detecting diabetic retinopathy–affected regions using clustering algorithms. Before applying segmentation, a series of preprocessing steps was carried out to enhance image quality and ensure reliable results. Retinal fundus images often suffer from uneven illumination, low contrast, and the presence of noise, which can make the identification of lesions such as microaneurysms, hemorrhages, and exudates difficult. To address these issues, preprocessing techniques including green channel extraction, histogram equalization, contrast normalization, and Gaussian filtering were implemented. These steps improved the visibility of small pathological features while reducing background interference. As reported in earlier studies, the use of preprocessing significantly improves segmentation accuracy by reducing false detections and enhancing lesion boundaries [11].

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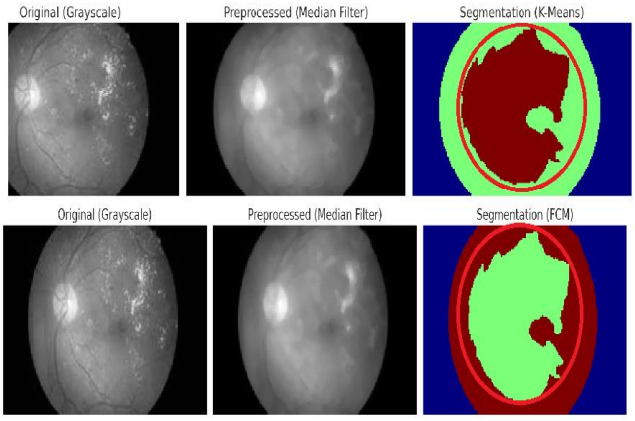


Figure 2. Shows the result of preprocessing and segmentation for the k-means and FCM Algorithms in diabetic patients' eye retina diseases identification.

Following preprocessing, two clustering Algorithms-**K-Means** and **Fuzzy C-Means (FCM)**-were applied and their performances compared (Figure 2). K-Means is a hard clustering algorithm where each pixel is assigned to exactly one cluster. This method was computationally efficient, requiring less time and memory, which makes it suitable for large-scale screening programs in resource-limited settings. In the present study, K-Means successfully separated major structures such as the optic disc and blood vessels from the retinal background. However, its limitations became apparent when dealing with small lesions and subtle abnormalities. Microaneurysms, which are among the earliest indicators of diabetic retinopathy, were often misclassified as normal background due to their low contrast and similarity in pixel intensity. This issue has also been highlighted in previous research, where K-Means was reported to underperform in cases involving heterogeneous lesion patterns [12]. In contrast, Fuzzy C-Means clustering demonstrated superior segmentation performance. Unlike K-Means, FCM allows pixels to have partial membership across multiple clusters, providing flexibility in cases where lesion boundaries are unclear or intensities overlap. This property proved valuable in segmenting diabetic retinopathy–affected regions, where exudates and hemorrhages often blend into surrounding tissues. In the present study, FCM generated smoother segmentation boundaries and preserved finer details, particularly in detecting early-stage microaneurysms and soft exudates. These findings align with the work of Gupta and Ramesh [13], who emphasized that FCM reduces false negatives and produces higher diagnostic accuracy compared to traditional clustering approaches. The impact of preprocessing was more pronounced in the FCM results. Noise reduction and contrast enhancement allowed FCM to make better use of the intensity variations in retinal images, further improving lesion detection. For instance, bright lesions such as hard exudates were more sharply distinguished from the retinal background, while dark lesions like hemorrhages showed clearer boundaries. This demonstrates that preprocessing not only enhances the overall quality of segmentation but also complements the strengths of soft clustering methods. When comparing the two methods, both have advantages depending on the application context. K-Means offers speed and simplicity, making it a potential choice for preliminary screening programs where thousands of images need to be processed quickly.

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However, its tendency to misclassify fine abnormalities limits its diagnostic value. On the other hand, FCM, although computationally more expensive, provides higher accuracy and better lesion delineation. Given that diabetic retinopathy diagnosis requires precision to prevent vision loss, FCM emerges as the more reliable approach for clinical use. The results of this study suggest that clustering-based segmentation methods, particularly FCM with adequate preprocessing, can play a crucial role in automated diabetic retinopathy detection systems. However, challenges remain in handling images with severe noise or advanced disease stages, where lesions overlap extensively. Future research may combine clustering with deep learning methods to improve robustness and scalability.

Conclusion

The analysis clearly indicates that both K-Means and FCM algorithms are capable of segmenting retinal images, but their suitability depends on the specific application. K-Means is computationally efficient and provides quick segmentation, making it suitable for large-scale screening tasks where speed is prioritized. However, its rigid clustering mechanism often fails to detect subtle lesions and overlapping vessel structures, which are crucial indicators in diabetic retinopathy. Fuzzy C-Means, although computationally more intensive, demonstrated superior segmentation accuracy by capturing finer pathological details, preserving vessel structures, and producing smoother boundary detection. This makes FCM more reliable for medical image analysis, where diagnostic accuracy is of utmost importance. Therefore, the study concludes that Fuzzy C-Means outperforms K-Means in terms of clinical relevance and diagnostic precision for diabetic retinopathy detection. K-Means may still be used as a supportive technique for rapid screening, but FCM should be considered the preferred algorithm for detailed medical image segmentation.

Authors' Assent and Recognition

Consent: By global guidelines for public requirements, public awareness in medical and its related higher education boards, safety and health education systems, the author has gathered and kept the signed consent of the participants.

Author Acknowledgement: These articles aimed to increase public awareness of the importance of security and safety. Sources that illustrate development and security are drawn from the relevant database to support the study's objectives. Don't make any assertions about readers, viewers, or authorities.

Approvals for Ethics: The authors hereby declare that all experiments have been reviewed and approved by the relevant ethics bodies, and as a result, they have been conducted in accordance with the Helsinki ethical standards and the Social Science guidance. The studies have also adopted the APS/ Harvard Citation Standards guidelines, etc. The authors abide by the publication regulations,

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