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High-resolution retinal imaging system: diagnostic accuracy and usability

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Abstract

The development of high-resolution retinal imaging systems is critical for enhancing the diagnostic accuracy and usability of tools used in detecting glaucoma and managing other ophthalmic and systemic diseases. This study evaluates a novel high-resolution retinal imaging system by comparing its diagnostic performance in detecting glaucoma with AutoMorph, a leading retinal vessel segmentation tool with available online code for reproducibility. The system's diagnostic accuracy was assessed using Area Under the Curve (AUC) metrics, with our system (HRVIAS) achieving a superior AUC of 0.7048 compared to AutoMorph's AUC of 0.6560. Additionally, a usability study was conducted using the System Usability Scale (SUS), where participants rated the system highly, with the majority of scores clustering around 80 to 85, indicating strong user satisfaction. These findings demonstrate that the proposed system not only improves the diagnostic accuracy of detecting glaucoma but also offers a user-friendly interface, making it a valuable tool for clinical and research applications in retinal imaging.

Keywords: *diagnostic accuracy, glaucoma detection, high-resolution retinal imaging, retinal vessel segmentation, system usability scale*

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Introduction

Retinal vessel segmentation is a critical component in the diagnosis and management of various ophthalmic and systemic diseases, including diabetic retinopathy (Radha & Karuna, 2024), glaucoma (Kortuem *et al.*, 2021), and cardiovascular conditions (Hanssen *et al.*, 2022). Accurate segmentation of retinal vessels enables the extraction of valuable biomarkers that can be used for early diagnosis (Ma *et al.*, 2023), monitoring disease progression (Leontidis *et al.*, 2015), and planning surgical interventions (Zhang *et al.*, 2021). Given the importance of this task, numerous methods have been

developed over the years to improve the accuracy, sensitivity, and specificity of vessel segmentation from fundus images and other retinal imaging modalities (Chen *et al.*, 2021).

Traditional approaches to retinal vessel segmentation have relied on manual techniques or basic image processing methods, which are often time-consuming and prone to human error. However, the advent of deep learning has revolutionized the field, leading to the development of more sophisticated algorithms that can automatically segment retinal vessels with high precision (Chen *et al.*, 2021). Among these, the Full-Resolution Network (FR-UNet) stands out for its ability to outperform state-of-the-art methods in both retinal vessel and coronary angiography segmentation (Liu *et al.*, 2022). This method achieves higher sensitivity and connectivity with fewer parameters by utilizing a multiresolution convolution interactive mechanism and a dual-threshold iterative algorithm (Liu *et al.*, 2022). The FR-UNet method was shown to significantly enhance vessel connectivity and improve segmentation performance across multiple datasets.

In parallel, several other innovative approaches have been proposed. For instance, Muzammil *et al.* introduced a multifilters-based unsupervised method for retinal blood vessel segmentation that effectively segments vessels in fundus images by employing a combination of contrast enhancement and morphological operations. This method provides a reliable tool for ophthalmologists in diagnosing various eye diseases (Muzammil *et al.*, 2022). Similarly, MIC-Net, a multi-scale integrated context network, has been designed to reduce small blood vessel segmentation errors, improving the overall accuracy of retinal vessel segmentation in fundus images (Wang *et al.*, 2023).

Furthermore, the need for enhanced sensitivity in retinal vessel segmentation has led to the development of a phase stretch transform (PST)-based edge detection scheme, which significantly improves sensitivity, especially in high-resolution fundus images (Firdausy *et al.*, 2022). This approach demonstrates a clear improvement over existing methods, highlighting the ongoing need for advancements in this area.

Other notable methods include SS-Net, a U-shaped network based on attention mechanisms, which improves disease diagnosis accuracy by accurately segmenting retinal vessels in optical coherence tomography angiography (OCTA) images (Jiang *et al.*, 2022a), and the use of B-COSFIRE filters for enhanced segmentation performance in fundus images (Li *et al.*, 2022). Additionally, the integration of transformers with convolutional neural networks in the MTPA_Unet model has shown significant improvements in segmentation accuracy across multiple public datasets (Jiang *et al.*, 2022b).

Moreover, AutoMorph, another advanced system, leverages a deep learning pipeline for automated analysis of retinal vascular morphology. This system, which has been made publicly available, has demonstrated its potential in facilitating ophthalmic and systemic disease research, particularly in oculomics (Zhou *et al.*, 2022). AutoMorph's approach to retinal vasculature analysis further exemplifies the ongoing evolution in this domain.

In this study, we aim to enhance retinal vessel segmentation techniques by evaluating and comparing different methods, focusing on their applicability to high-resolution retinal images and their potential clinical impact. Specifically, we compare our approach with AutoMorph, a publicly available method, to ensure reproducibility and consistent benchmarking. The objectives of this study are to (1) assess the diagnostic accuracy of HRVIAS in comparison to AutoMorph and (2) evaluate its usability using the System Usability Scale (SUS) to determine its feasibility for integration into research and clinical workflows.

Materials and Methods

Data selection and image processing methodology

In this study, we utilized a subset of the FIVES dataset (Jin *et al.*, 2022), which is a high-resolution colour fundus image collection. From this dataset, we initially selected 400 images, comprising 200 cases diagnosed with glaucoma and 200 cases with no detectable pathology (Che Azemin *et al.*, 2024). This selection was intended to provide a balanced representation of both pathological and healthy retinal conditions.

To ensure the quality and reliability of the images used for analysis, we employed the built-in AutoMorph quality assessment system (Zhou *et al.*, 2022). This system automatically evaluates the quality of each image, filtering out those that do not meet the necessary standards for accurate analysis. Only images deemed gradable by this assessment were included in the subsequent processing steps, ensuring that our analysis was conducted on images of sufficient quality (Ribeiro Reis *et al.*, 2024).

Following the quality assessment, the images were processed independently by two systems: HRVIAS and AutoMorph. Each system is designed to isolate and analyse the retinal blood vessels, separating them from the background of the fundus image. This vessel segmentation is a crucial step in the analysis, as it allows for a focused examination of the vascular network, which is essential for calculating the fractal dimension (Che Azemin *et al.*, 2024). HRVIAS employed a state-of-the-art high-resolution blood vessel segmentation technique based on IS-Net architecture (Che Azemin *et al.*, 2025).

Both HRVIAS and AutoMorph utilise the box-counting method to determine the fractal dimension of the retinal vasculature (Che Azemin *et al.*, 2016). This method provides a quantitative measure of the complexity and branching patterns of the blood vessels, which can be used to assess differences between glaucomatous and healthy eyes. The output of this analysis provides insights into the structural characteristics of the retinal vessels, which may differ between the pathological and non-pathological cases.

Through this methodology, we aimed to compare the capabilities and outputs of the HRVIAS and AutoMorph systems in analysing high-resolution retinal images, with a focus on the accuracy and reliability of the fractal dimension calculations derived from the FIVES dataset.

Technical specifications

Table 1 presents a comparison of the technical specifications between two systems, AutoMorph and HRVIAS, which are used for analysing retinal vasculature. The comparison focuses on three key aspects: resolution, segmentation capabilities, and the method used for determining the fractal dimension of the vasculature.

Table 1. Comparison of technical specifications between AutoMorph (AM) and HRVIAS systems, focusing on resolution, segmentation capabilities, the method used for calculating the fractal dimensions of retinal vascular, and the interface used.

| System | Technical Specifications | | | |
	Resolution (pixels)	Segmentation	Fractal Dimension Method	Interface
AutoMorph	912	Whole vessel and Artery/Vein	Box counting	Google Collab
HRVIAS	2048	Whole vessel	Box counting	GUI

The resolution of the images processed by each system differs significantly. AutoMorph operates with a resolution of 912 × 912 pixels, whereas HRVIAS utilizes a much higher resolution of 2048 × 2048 pixels. This difference in resolution suggests that HRVIAS may capture more detailed images, which could be advantageous for analysing finer structures within the retinal vasculature.

In terms of segmentation, AutoMorph offers more advanced capabilities. It is not only capable of segmenting the entire vessel structure but also differentiates between arteries and veins within the retinal images. On the other hand, HRVIAS is designed to segment the whole vessel structure without distinguishing between the different types of blood vessels. This indicates that AutoMorph may provide more detailed and specific vascular analysis, potentially offering more comprehensive insights into retinal health.

Both systems employ the box counting method to calculate the fractal dimension of the retinal vasculature. The fractal dimension is a crucial metric used to describe the complexity of the vascular network. By using the same method, it allows for a standardized approach to assessing vascular patterns across different systems, even though the resolution and segmentation capabilities differ between AutoMorph and HRVIAS.

For the AutoMorph system, the interface is based on Google Colab, which is a cloud-based platform allowing users to run and interact with code in a web-based environment. This suggests that AutoMorph is likely designed for users familiar with coding or technical environments. On the other hand, HRVIAS uses a Graphical User Interface (GUI) as illustrated in Figure 1, which typically offers a more user-friendly, visual interaction method, making it more accessible to users who may not have technical coding skills.
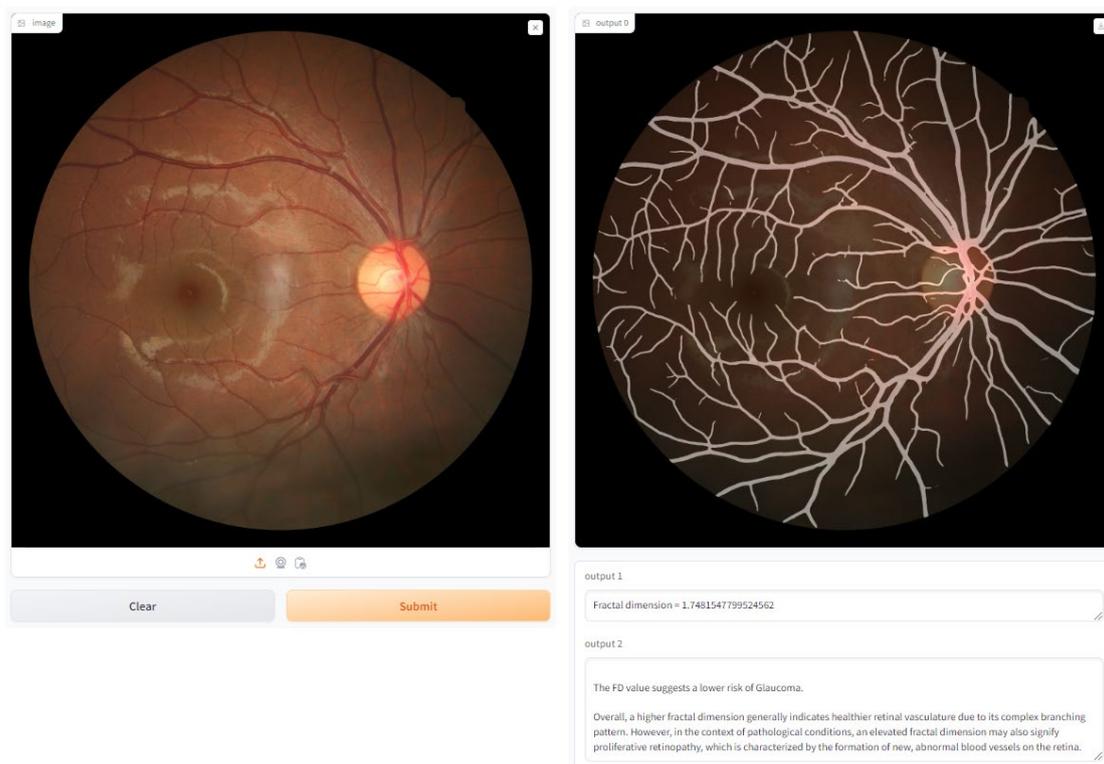

Figure 1. Screenshot of the HRVIAS interface showing a retinal image with its vascular network, along with the calculated fractal dimension and glaucoma risk assessment, indicating a healthy vasculature.

Usability study

To assess the usability of HRVIAS, we conducted a study using the System Usability Scale (SUS). The SUS is a widely recognized tool for measuring the usability of a system and provides a single score that reflects the overall usability of a product or service (Lewis, 2018). For this study, 13 participants were selected, including resident optometrists, visiting optometrists, lecturer optometrists, and non-clinical staff working at an optometry premise. Each participant independently interacted with the system and provided their assessments based on the predefined evaluation criteria. These participants were chosen to ensure that the feedback collected was representative of the system's actual end-users.

In usability studies, small sample sizes are common because the primary goal is to identify major usability issues rather than to statistically generalize findings to an entire population. Nielsen (1994) and Virzi (1992) demonstrated that testing with as few as five participants can uncover approximately 80–85% of usability problems, with additional users often providing diminishing returns in terms of new insights. Moreover, Faulkner (2003) supports the notion that increasing the number of participants beyond a certain threshold typically yields minimal additional benefits. In our study, a sample of 13 participants—which included optometrists and other potential users—was chosen to ensure a diversity of perspectives while still aligning with these established guidelines in usability research. This sample size allowed us to gather robust user feedback and obtain reliable SUS scores that reflect the overall user experience, making it a justified and effective choice for our formative usability evaluation.

Participants were asked to respond to a series of statements regarding their experience using the retinal image analysis tool, and they provided their level of agreement on a 5-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree) (Lewis, 2018; Lewis & Sauro, 2018).

In the SUS evaluation, participants were asked to respond to ten statements regarding the retinal image analysis tool. These statements covered a range of opinions, including their likelihood to use the tool regularly for assessing vascular health; whether they found the tool unnecessarily complex or, conversely, easy to use; and if they believed they would require technical support to operate it. Other statements focused on the integration of the tool's functions, the consistency of its design, the ease with which most users could learn to use it, the degree to which it felt cumbersome, their overall confidence when using the tool, and the initial learning effort required before getting started.

To calculate the SUS score, each participant's responses were converted using a standardized method. For the odd-numbered statements (1, 3, 5, 7, and 9), 1 was subtracted from the participant's score, while for the even-numbered statements (2, 4, 6, 8, and 10), the participant's score was subtracted from 5. The adjusted scores from all ten statements were then summed to yield a total score ranging from 0 to 40. Finally, this sum was multiplied by 2.5 to convert the total into a SUS score out of 100.

The SUS score is interpreted based on a threshold of 68, where a score above 68 is considered to indicate above-average usability, suggesting that the system is generally well-received and user-friendly (Lewis, 2018; Lewis & Sauro, 2018). Conversely, a score below 68 is regarded as below average, indicating that the system may have usability issues or areas that require improvement to meet users' expectations and needs effectively. This scoring system provides a quick and reliable way to assess whether a tool or system is likely to be user-friendly or in need of further refinement.

Result

Figure 2 shows the Receiver Operating Characteristic (ROC) curves for two retinal image analysis systems, AutoMorph (AM)

and HRVIAS. The ROC curve is a plot of the True Positive Rate (sensitivity) against the False Positive Rate (1-specificity) across various threshold settings, providing insight into the diagnostic accuracy of the systems.

The Area Under the Curve (AUC) is used to quantify the overall performance, with a higher AUC indicating better discriminative ability.
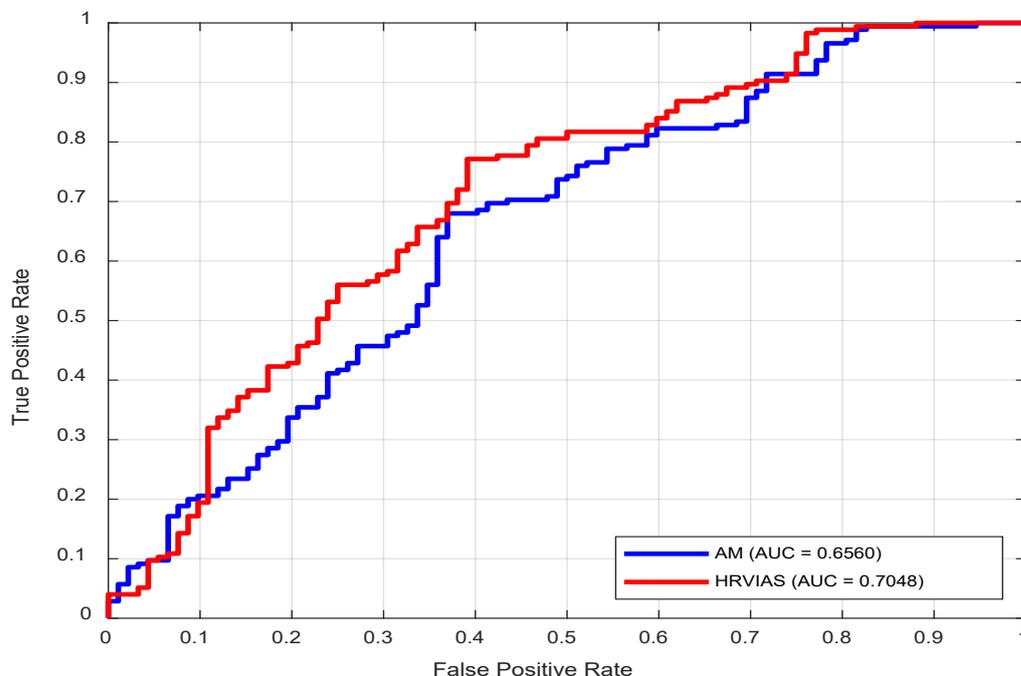

Figure 2. Receiver Operating Characteristic (ROC) curve for differentiating between glaucoma and normal cases using AutoMorph (AM) and High-Resolution Retinal Imaging System (HRVIAS systems).

An AUC of 1.0 represents perfect classification, meaning the system perfectly distinguishes between the positive and negative classes without any errors. Conversely, an AUC of 0.5 indicates a performance equivalent to random chance, where the system has no discriminative ability.

In this figure, the AUC for HRVIAS is 0.7048, which is higher than the AUC for AutoMorph, which is 0.6560. Although the difference did not reach statistical significance, these results indicate that HRVIAS may exhibit a modest advantage in differentiating between positive and negative cases in this dataset. Although both systems show moderate performance, HRVIAS outperforms AutoMorph in this particular analysis, indicating its superior ability to correctly classify retinal images in the context of this study.

As shown in Figure 3, the distribution of System Usability Scale (SUS) scores indicates that most participants rated the usability of the system between 80 and 85, suggesting a generally positive user experience.

Discussion

The findings of this study demonstrate that the proposed high-resolution retinal imaging system offers a modest but meaningful improvement in diagnostic accuracy for glaucoma detection compared to AutoMorph, as evidenced by the higher AUC (0.7048 vs. 0.6560). This aligns with previous research emphasizing the importance of high-resolution imaging in retinal vessel segmentation and its impact on diagnostic precision (Chen *et al.*, 2021; Liu *et al.*, 2022). The superior performance of HRVIAS may be attributed to its higher

resolution (2048 × 2048 pixels) compared to AutoMorph (912 × 912 pixels), which likely enables the capture of finer vascular details critical for accurate segmentation and disease detection (Che Azemin *et al.*, 2024).

This is consistent with the findings of Firdausy *et al.* (2022), who highlighted the role of high-resolution imaging in improving sensitivity for retinal vessel segmentation.
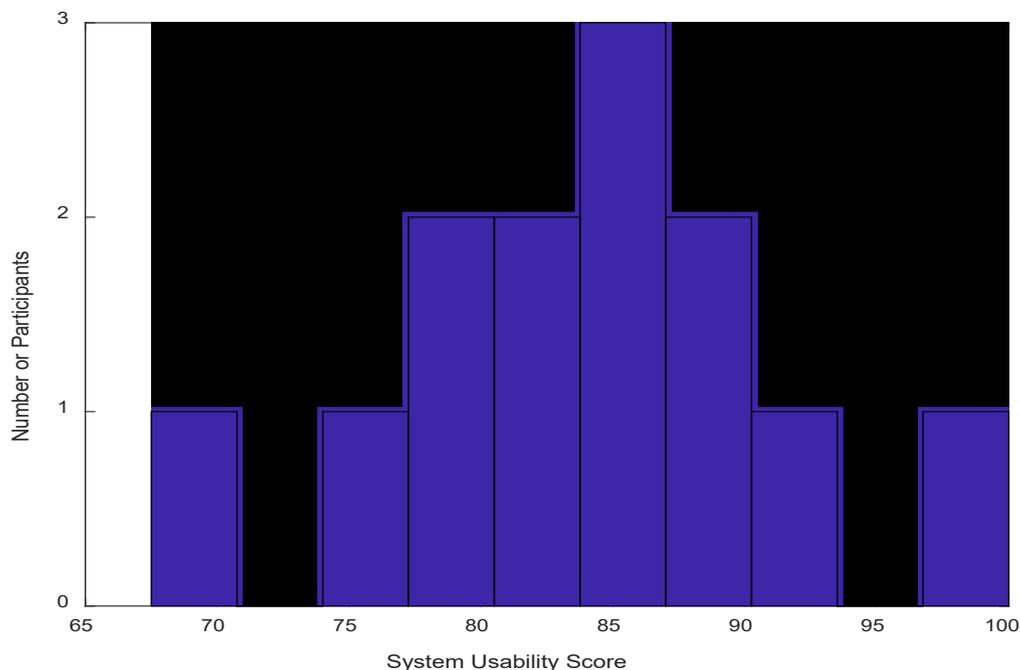

Figure 3. Distribution of System Usability Scale (SUS) scores among participants. The histogram shows the number of participants corresponding to different SUS score ranges. The scores are spread across a range, with the majority of participants scoring around 8.

The usability study further underscores the potential of HRVIAS for clinical adoption. With SUS scores clustering between 80 and 85, the system was rated as highly user-friendly, a critical factor for its integration into clinical workflows. This is particularly important given the increasing reliance on automated tools in ophthalmology, where user satisfaction and ease of use are key determinants of adoption (Lewis, 2018). The graphical user interface (GUI) of HRVIAS, as opposed to the code-based interface of AutoMorph, likely contributed to its higher usability scores, making it more accessible to clinicians without technical expertise (Lewis & Sauro, 2018). This finding is consistent with usability research by Faulkner (2003), which emphasizes the importance of intuitive design in enhancing user experience and reducing the learning curve for new systems.

However, it is important to acknowledge the limitations of this study. While HRVIAS demonstrated a higher AUC, the difference was not statistically significant, suggesting that further validation on larger datasets is necessary to confirm its diagnostic superiority. Additionally, the usability study, though informative, was conducted with a relatively small sample size (n = 13). While small sample sizes are common in usability studies and can effectively identify major usability issues (Nielsen, 1994; Virzi, 1992), future studies should include a broader and more diverse user base to generalize these findings.

The comparison with AutoMorph also highlights areas for improvement. AutoMorph's ability to differentiate between arteries and veins provides a more detailed vascular analysis, which could be beneficial for certain clinical applications (Zhou *et al.*,

2022). Integrating similar capabilities into HRVIAS could further enhance its utility. Additionally, the use of advanced segmentation techniques, such as the Full-Resolution Network (FR-UNet) employed by Liu et al. (2022), could be explored to improve the connectivity and accuracy of vessel segmentation in HRVIAS.

The implications of this study extend beyond glaucoma detection. Retinal vessel segmentation is a critical tool for diagnosing and managing a range of ophthalmic and systemic conditions, including diabetic retinopathy and cardiovascular diseases (Hanssen *et al.*, 2022; Radha & Karuna, 2024). The improved diagnostic accuracy and usability of HRVIAS make it a promising tool for broader clinical and research applications. For instance, its high-resolution capabilities could be leveraged to study subtle vascular changes associated with systemic conditions, as highlighted by Ma *et al.* (2023).

Conclusion

This study evaluated a novel high-resolution retinal imaging system (HRVIAS) for glaucoma detection, demonstrating that it achieved an AUC of 0.7048 compared to AutoMorph's 0.6560. Additionally, usability testing using the System Usability Scale yielded high scores (between 80 and 85), indicating strong user satisfaction. These results suggest that HRVIAS not only enhances diagnostic accuracy through improved retinal vessel segmentation but also offers a user-friendly interface, making it a promising tool for both clinical practice and future research.

Acknowledgment

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