Advances in Transdisciplinary Engineering series

volume 67

Data, Information and Computing Science

Proceedings of the 2nd International Conference (CDICS 2024), Singapore, 6-8 December 2024

EDITED BY
Anand Nayyar
Tok Wang Ling
Carson Leung

IOS Press

DATA, INFORMATION AND COMPUTING SCIENCE

Advances in Transdisciplinary Engineering

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ISSN 2352-751X (print)
ISSN 2352-7528 (online)

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Sage | IOS Press

ISBN 978-1-64368-576-2 (online)
doi: 10.3233/ATDE67

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Preface

The 2nd International Conference on Data, Information and Computing Science (CDICS 2024) was held in Singapore from 6 to 8 December 2024. This conference offered a platform for academics, scientists, researchers, and experts to express and discuss their interests in data, information and computing science.

The conference invited three keynote speakers to share their latest research: Prof. Sergei Gorlatch, from the University of Muenster; Prof. Teh Ying Wah from the University of Malaya; and Prof. Anand Nayyar from Duy Tan University. Each speaker delivered a 45-minute keynote. The conference also included 2 oral sessions and I poster session. CDICS 2024 provided an effective communication platform for all those participants who took the opportunity to share their research results and discuss potential scientific and engineering developments arising from their work.

The CDICS 2024 conference received 44 paper submissions, of which 10 papers were accepted. These cover all aspects of computers, information and data ranging from theoretical foundations to novel models, algorithms and applications, including: computer vision, image processing, machine learning, data analysis, networking, and artificial intelligence. All the papers included here passed a rigorous peer-review process by members of the technical program committee and professional reviewers. The variety and novelty of the research topics presented at the conference and exhibited in the papers as published in this book demonstrate the impact of CDICS 2024.

We would like to acknowledge all of those who supported CDICS 2024; the help received from individuals and institutions was very important for the success of this conference. In particular, we would like to thank committee chairs, committee members and reviewers for their tremendous contribution to the organization of the conference and the peer reviewing of papers.

CDICS2024 was a forum for excellent discussions that put forward new ideas, promoted collaborative research, and will support researchers as they take their work forward. We are sure that the book will serve as an important source of references and knowledge for research, which will lead not only to scientific and engineering progress, but also to novel products and processes.

The Editors

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Review Process

All submissions to the CDICS 2024 will be reviewed, the papers will go through the editorial process consisting of two stages: Preliminary review and Peer-Review

Preliminary Review: CDICS Editors perform a preliminary review of the manuscript's suitability to ensure the submission falls within the scope of the conference upon receipt. Preliminary Review is set to check the fundamental elements of the manuscript such as topic, layout, structure, length, language, originality, references and competing interest etc. And each manuscript will be checked if it has potential problem of plagiarism (iThenticate). Papers not passing the plagiarism checking or the topic is out of the conference will be rejected immediately.

Peer Review: Only the papers passed the preliminary review will be double-blind peer-reviewed by at least 2 independent reviewers. Reviewers evaluate submissions based on the requirements of the conference proceedings, predefined criteria, and quality, completeness, originality and grammar of the research presented. Also, reviewers are asked to respond to a short questionnaire that serves as a Reviewer's checklist and ensures a standardised, comprehensive review.

Authors are required to respond to the peer review comments in details and make minor or major revisions according to the points raised. Usually, one round of major revisions is allowed. Acceptance is granted when reviewers' recommendations are positive. In cases of strong disagreement between the reviewers or between the Authors and Reviewers, the Editor can assess these according to his/her expertise or seek advice from a member of the program board.

Number of submitted papers and accepted papers:

Submitted papers: 44
Accepted papers:10
Acceptance rate: 23%

Contents

Data, Information and Computing Science
A. Nayyar et al. (Eds.)

doi:10.3233/ATDE250008

Optimized Retinal Vessel Segmentation Using IS-Net and High-Resolution Dataset

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Abstract. Segmentation of the retinal vessels is extremely useful and very important in the diagnosis and management of various diseases associated with the eye, including diabetic retinopathy and glaucoma. The work has presented an improved methodology using an IS-Net model trained on the high-resolution FIVES dataset, including 800 annotated images of the retina. This paper therefore resolves the proposed approach by pre-processing, which consists of normalizing and performing horizontal flipping, followed by enhancement using IS-Net and histogram-based thresholding criteria for vessel structure binarization. The IS-Net architecture is designed with multi-scale RSU blocks to capture both fine and broad vessel details comprehensively for segmentation. Results have shown that IS-Net achieves a good balance in recall and specificity, with the F1 score high enough to outperform other models in terms of specificity by reducing false positives. These findings underlined the effectiveness of IS-Net for clinical applications and emphasized the value of high-resolution data for refinement in the performance of segmentation.

Keywords. Retinal vessel segmentation, IS-Net, high-resolution fundus imaging, FIVES dataset, Otsu's thresholding, deep learning, medical image analysis, encoder-decoder architecture, RSU blocks, ophthalmic diagnostics, vessel enhancement, specificity, recall, automated diagnosis, pixel-wise annotation

1. Introduction

The most fundamental activity in the analysis of retinal vasculature involves first enhancing and then binarizing the blood vessels. Segmentation is thus the very heart of facilitating diagnostic and monitoring activities in ophthalmology. Binarization, in particular, forms an important stage where the enhanced vessel structures must be translated into a clear and discernible binary representation distinguishing the vessels from the background. This is an important step in correct visualization and its subsequent clinical interpretation; it bears a direct relationship to diagnosis and management, not only of ocular diseases but also systemic ones, including diabetic retinopathy, glaucoma, and hypertension. Such accurate segmentation will be crucial clinically, as this will enable clinicians to monitor continuous changes in disease severity.

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These changes, mapped in the retinal vasculature over time, help the health professional evaluate treatment methodologies and make necessary informed adjustments accordingly. Furthermore, precise segmentation facilitates the analysis of vascular abnormalities, including abnormalities in diameter, tortuosity, and complexity, possibly as manifestations of more general conditions or early disease states [1,2]. These abnormalities can serve as biomarkers for systemic health conditions, offering insights across different ophthalmic conditions.

2. Related works

2.1. Challenges in High-resolution Retinal Vessel Segmentation

It is difficult to handle interaction variability from blood vessel caliber changes, uneven illumination, and noise using conventional image-processing approaches for high-resolution images [3,4]. Deep learning has brought significant advancements, and works using models like U-Net and its derivatives are performing well [1,5]. These architectures mostly depend on an encoder-decoder configuration that normally causes degradation in capturing the subtle details, since the down-sampling processes inhibit the detection of finer and uneven illumination blood vessels [3,6].

2.2. Current Solutions in High-resolution Retinal Vessel Segmentation

A number of mechanisms have been put forth to tackle these issues. For example, Guo [3] proposed a detail-preserving network that retains high-resolution data throughout the framework and is helpful for enhancing segmentation for finer blood vessels. Ye et al. [1] proposed another approach by introducing high-resolution architecture with strip attention modules to preserve the dependent information in both horizontal and vertical directions and enhance the quality of segmentation of the small blood vessels.

Advanced architectures including attention mechanisms and transformer networks have equally shown promise towards better segmentation performance. Lin et al. [9], proposed the Stimulus-Guided Adaptive Transformer Network, which adaptively adjusts the receptive fields to capture the changeable scale of the retinal vessels. Their approach responds to the problem of the high similarity in visual features between lesions and vasculature, which often causes segmentation errors.

Despite such developments, certain challenges persist in the efficient segmentation of the retinal vessels within high-resolution images, especially regarding noise elimination and vessel detection with a variety of diameters. The enhancement in pre-processing techniques-for example, using an improved padding technique developed by Ali et al. [6], tends to reduce false positives near the edges of the image, thus enhancing overall segmenting performance.

2.3. Choice of Dataset in High-resolution Retinal Vessel Segmentation

High-resolution imaging of the fundus has, therefore, been a key factor in achieving higher diagnostic accuracy, especially in diagnosing complex ophthalmic conditions. Che Azemin et al. [7] have demonstrated that fractal dimension analyses are highly dependent on image resolution, leading to significant improvements in detecting and differentiating conditions like diabetic retinopathy and glaucoma. The value of deep learning models in blood vessel segmentation has also risen substantially due to large, annotated datasets. Among these, the FIVES dataset stands out as a premier resource due to key attributes that differentiate it from existing ones [8].

First, the FIVES dataset presents unmatched image quality, with 800 high-resolution fundus images, each with pixel-wise annotations. The 2048×2048-pixel resolution captures even the smallest details of the retinal vasculature, enabling more accurate and robust segmentation. Unlike lower-resolution datasets, FIVES minimizes the loss of intricate vessel structures that can be critical for precise diagnosis and research.

The detailed pixel-wise annotations in the FIVES dataset enhance its utility by providing an accurate ground truth for model training and evaluation. These high-quality annotations are essential for training segmentation models that need to differentiate between fine vessel networks and background tissue effectively. Moreover, the large size of the dataset aids in enabling deep learning models to generalize better, increasing their robustness when applied to real-world scenarios with varying image qualities and pathologies.

Compared to publicly available datasets like DRIVE, STARE, and CHASE_DB1, which typically have lower image resolutions or limited annotated samples, FIVES offers a more comprehensive, high-resolution dataset that addresses these limitations. While these earlier datasets were foundational for initial developments in retinal segmentation, they do not meet the growing high-resolution data demands of modern deep learning models.

The FIVES dataset thus provides a substantial advantage by combining high image resolution with a large number of annotated images, facilitating the development of more accurate and sophisticated blood vessel segmentation algorithms. Its comprehensive nature supports a broader range of experiments and model evaluations, allowing researchers to test their algorithms against diverse data conditions. This diversity helps models trained on FIVES adapt better to various clinical scenarios, enhancing their applicability and reliability in different diagnostic settings.

We propose, in this work, an optimized approach for retinal vessel segmentation using the IS-Net model [10] on training with a high-resolution FIVES dataset [8]. The proposed architecture of IS-Net is designed to capture multi-scale features through an encoder-decoder structure specifically designed for better preservation of spatial details and enhance feature extraction capabilities with RSU blocks [10]. The approach that we propose, taking advantage of the high-resolution images, and by integrating efficient pre-processing techniques, will pursue finer and uneven illumination retinal vessels, which are very crucial in early disease detection.

3. Methodology

3.1. Proposed Framework for High-resolution Retinal Vessel Segmentation

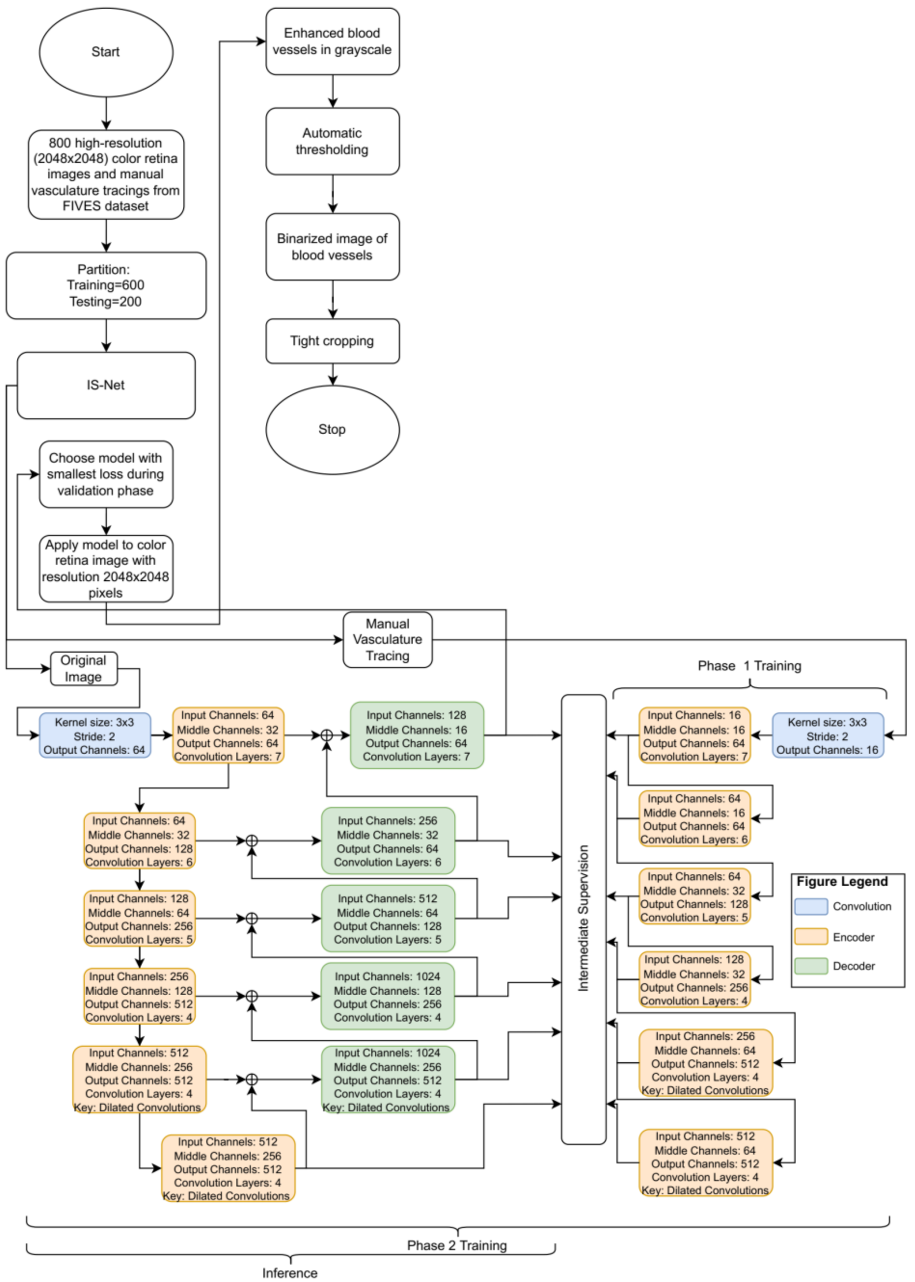

Figure 1. Flowchart of the retina image segmentation framework using the IS-Net model and FIVES dataset.

Figure 1 illustrates the flowchart of the IS-Net model in segmenting the retina images, which are trained on the FIVES dataset. The dataset contained 800 high-resolution retinal images annotated with manually labeled blood vessel maps. The original images were of size 2048×2048 pixels; 600 images were utilized for training, and the remaining 200 images for the testing set. Preprocessing in this pipeline involves normalization, with horizontal flipping for augmentation. Further, Otsu's thresholding method is applied on the gray-scale images of blood vessels to perform binarization. This is an optimum automatic selection of the threshold value based on a histogram of an image. This helps ensure that the vessels are segmented out from the background with much less manual tuning of parameters.

The IS-Net model architecture is built with an encoder-decoder structure, optimized for capturing multi-scale features, essential for retinal vessel segmentation. The encoder comprises Residual U-Net (RSU) blocks, specifically RSU7, RSU6, RSU5, RSU4, and RSU4F, each configured with varying input and middle channel sizes to capture details at multiple scales. These RSU blocks include convolutional layers, batch normalization, and ReLU activation functions that enhance feature extraction capabilities. The decoder section mirrors the encoder, using upsampling layers and concatenations to reconstruct the image and refine the segmentation progressively, ensuring that the final output matches the input resolution.

Training the model involves optimizing it using the Adam optimizer, which is initialized with a learning rate of 1×10^{-3}. This optimizer is chosen for its effectiveness in adjusting the learning rate for each parameter, aiding in faster convergence. The primary loss function used is a binary cross-entropy loss computed over multiple outputs. When intermediate supervision is enabled, an additional mean squared error (MSE) loss is computed, which compares intermediate feature outputs with ground truth features, adding robustness to the learning process. The training process iterates over mini-batches, calculating the loss, performing backpropagation, and updating the weights. Training metrics such as the loss and running averages are displayed to monitor progress.

Validation is conducted at intervals to ensure that the model generalizes well. This step involves running the model on a separate validation set, rescaling the predicted outputs to match the original input size, and calculating performance metrics such as the F1 score and mean absolute error (MAE). The best-performing model, defined by achieving the highest F1 score, is saved during this process, ensuring that the training focuses on models with superior performance. An early stopping mechanism is also incorporated to halt training when no improvement is detected over a specified number of validation periods, preventing overfitting.

During inference, the trained IS-Net model is applied to unseen high-resolution retinal images to produce blood vessel segmentation maps. The robust feature representations learned during training enable the model to accurately delineate blood vessels, capturing even fine and complex structures. The IS-Net model's ability to utilize multi-scale features through its RSU blocks makes it particularly effective for this application. The architecture's combination of deep and shallow features ensures that the output captures both broad vessel structures and intricate details.

The IS-Net incorporates specific RSU blocks, each contributing to its multi-scale feature extraction capability. RSU7 starts the process with an initial set of convolutions and pooling, focusing on capturing low-level features. RSU6, RSU5, and RSU4 progressively extract more complex features, using deeper layers and max-pooling for down-sampling while retaining essential context. RSU4F, with dilated convolutions, expands the receptive field, allowing the network to capture finer vessel details without losing spatial resolution. The decoder section complements this by using upsampling and merging feature maps from the encoder stages, reconstructing a detailed output that closely matches the ground truth.

3.2. Performance Metrics in Retinal Vessel Segmentation

Performance metrics of such tasks usually include True Positives (TP), False Negatives (FN), False Positives (FP), and True Negatives (TN), which are important to realize how the model is performing well. The measures provide a description of how the balance between proper identification of the vessels and reduction of misclassifications is maintained in order to preserve the quality of segmentation.

TP refers to those pixels of blood vessels that the segmentation model identifies correctly. That is, if a pixel from the actual or ground truth image belongs to a vessel and the model correctly segments it as a vessel, then it becomes a true positive. High TP values will present an indication that the model will perform well in the detection of vessel structures. This is very significant for diagnostic purposes in medical fields, such as identifying abnormalities in the retinal images.

FN is the pixels of blood vessels that, from the ground truth, were not detected by the model and instead were classified as background. If vessel pixels are not detected, the segmentation result may be incomplete. High values of FN are undesirable because they may hint that the model will probably fail to capture all the relevant vessel structure and maybe even skip some critical diagnostic features in medical images.

FP occurs when the model mistakenly segments pixels as vessels when they are actually part of the background in the ground truth image. This over-segmentation results in non-vessel regions being falsely marked as vessels, which can reduce the overall specificity of the model. Excessive FP values can introduce noise in the segmentation output, thus making it hard for a medical professional to obtain accurate diagnostics from automated analysis.

TN refers to correct identification of background pixels by that model. These are areas which do not belong to any vessel in the ground truth and which the model accurately segments as non-vessel. High values of TN indicate that the model can clearly identify vessel and non-vessel regions, hence giving high specificity and reducing false alarms.

Overall, the balance between maximizing true positives and true negatives while minimizing both types of false positives and false negatives comes into play to make a blood vessel segmentation model effective. This balance will ensure that the segmentation results are sensitive, hence capable of depicting the vessels accurately, and specific, hence capable of avoiding misclassification of non-vessel areas.

Based on TP, FN, FP, and TN, performance metrics could be derived. Recall, specificity, and F1-score will be some of the key metrics in finding the performance of a segmentation model, especially in medical imaging like blood vessel segmentation. Recall reflects how the model has performed with respect to correctly detecting true positives, that is, actual vessel pixels. Specificity shows how the model performs in terms of correctly determining true negatives, thereby describing how well it can refrain from classifying background pixels as vessels. The F1-score is the balanced mean of precision and recall. It is an overall measure that features both the exactness of positive identifications and the ability to avoid false negatives, especially useful when datasets are imbalanced and precision and recall need to be weighed together.

$$Recall\ (RC) = TP / (TP + FN) \tag{1}$$

$$Specificity\ (SP) = TN / (TN + FP) \quad (2)$$

$$F1\text{-}score\ (F1) = (2 \times TP) / (2 \times TP + FP + FN) \quad (3)$$

4. Results and Discussion

In Table 1, IS-Net shows a strong performance when compared to other state-of-the-art models for blood vessel segmentation on the FIVES dataset [9], both with intermediate supervision enabled (IS-On) and disabled (IS-Off). When intermediate supervision is turned on, IS-Net achieves the highest specificity (SP) at 99.55%, indicating its exceptional ability to minimize false positives and accurately identify non-vessel pixels. This precision is crucial for applications where avoiding false alarms is essential.

Table 1. Comparative analysis of blood vessel segmentation performance on the FIVES dataset. Bold values indicate the best-performing model for each specific metric.

Segmentation Method	RC %	SP %	F1 %
TransU-Net	**91.80**	99.22	90.37
SegNet	84.84	98.99	85.09
SGAT-Net	91.62	99.33	**90.51**
IS-Net IS-On	88.38	**99.55**	89.78
IS-Net IS-Off	90.37	99.27	88.70

However, the recall (RC) for IS-Net (IS-On) is slightly lower at 88.38%, which means it is somewhat less effective in capturing all true vessel pixels compared to models like TransU-Net and SGAT-Net. Despite this, the F1 score of 89.78% shows that IS-Net still maintains a strong balance between recall and precision, highlighting its robustness.

When intermediate supervision is turned off (IS-Off), IS-Net's recall improves to 90.37%, making it competitive with TransU-Net and SGAT-Net in terms of vessel detection. However, this configuration slightly reduces its specificity to 99.27%, and the F1 score also drops to 88.70%. This trade-off indicates that intermediate supervision enhances IS-Net's ability to avoid false positives, even if it may slightly compromise recall.

To address potential concerns regarding the computational complexity of IS-Net, it is important to highlight the modifications made in its architecture to enhance memory efficiency without sacrificing segmentation accuracy. The IS-Net model, adapted from the original U^2-Net, incorporates an input convolution layer before the first encoder stage to manage high-resolution inputs more effectively. This layer employs a 3×3 kernel with a stride of 2, reducing the input size by half before passing the feature map into the main network. This modification significantly decreases the overall GPU memory overhead by approximately three-quarters while retaining the spatial information needed for detailed segmentation. While IS-Net may exhibit a slightly lower recall compared to models like TransU-Net and SGAT-Net, its highest specificity among tested models highlights its precision, which is essential in clinical applications to minimize false positives. Future work will focus on exploring hybrid strategies that can leverage IS-Net's strengths while incorporating techniques to boost recall, ensuring a balanced optimization of both performance metrics.

5. Conclusion

Overall, IS-Net distinguishes itself by achieving the highest specificity among the models tested, demonstrating its effectiveness in scenarios that require high precision. While SGAT-Net achieves the highest F1 score (less than 1% difference than IS-Net IS-On), showing the best overall balance of metrics, IS-Net stands out for its adaptability with or without intermediate supervision, offering flexibility depending on the specific demands of the segmentation task. This makes IS-Net a competitive option for precise blood vessel segmentation when compared to other state-of-the-art methods.

Acknowledgement

This study was supported by the Ministry of Higher Education, Malaysia, under the Prototype Research Grant Scheme PRGS/1/2023/ICT02/UIAM/02/1. We declare that we have used OpenAI's ChatGPT to assist in improving the readability and clarity of this manuscript. The authors take full responsibility for the content of the manuscript, including any edits suggested by ChatGPT.

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