**Original Research Article**

# Enhanced vessel detection using edge detection and wavelet fusion for diabetic retinopathy detection

## Cristian-Dragoș Obreja[1*]

[1]Department of Materials and Environmental Engineering, Faculty of Engineering, "Dunarea de Jos" University of Galati 47 Domneasca, 800008 Galati, Romania
[*]Corresponding author email: **cristian.obreja@ugal.ro**

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## Abstract

This paper explores an image-based diagnostic model for early detection of diabetic retinopathy using medical image processing techniques. Using a database, which contains images from both healthy individuals and patients with diabetic retinopathy, there search applies a sequence of preprocessing steps including CLAHE, normalization and noise reduction. Two edge detection algorithms, Canny and Frangi, were applied to highlight vascular structures, and the output was used by wavelet-based image fusion to enhance detail clarity. The effectiveness of each method was evaluated using structural similarity metrics and mean percentage error, with results indicating improved vessel detection and diagnostic accuracy when preprocessing was optimized. The study proved robust performance in identifying different features from normal anatomy, suggesting that the integration of advanced image processing with statistical validation can significantly enhance retinal screening. This methodology supports more precise, early-stage clinical assessment and offers promising potential for future diagnostic systems.

## Key words

Vessel segmentation, Diabetic retinopathy, Edge detection, Wavelet fusion method, Retinal vessel analysis.

## Introduction

The vascular tree, consisting of arteries, veins, and capillaries, transports vital substances between the heart and body tissues, enabling systemic homeostasis. Its susceptibility to a variety of pathologies with severe health implications further underlines the need for sophisticated detection and intervention methods. Different approaches for vascular morphology assessment are studied in order to find vascular abnormalities. As part of biomedical engineering, this research develops non-invasive diagnostic techniques by the use of technological solutions. Particular attention will be paid to microvascular changes related to diabetic retinopathy [1].

Advanced imaging methods, like optical tomography, are tested for retinal vascular analysis. Furthermore, digital image processing techniques are applied to quantify changes associated with diabetic retinopathy. The goal is to create an accurate method to aid early diagnosis and disease monitoring, and to integrate engineering and clinical practice in order to contribute to improved care and prevention of vision-threatening complications [1-5].

Medical image processing is the focal point of computer-assisted diagnosis and therapy. It enables interpretation of anatomical and functional data across imaging modalities. Also, it improves segmentation, feature extraction and abnormalities detection. Techniques such as filtering, contrast enhancement and classification enhance diagnostic accuracy and help treatments. By integrating clinical workflows we improve objective decision-making, reduce variability in interpretation and improve intervention efficiency [4-7].

## Materials and methods

### Database

The DRIVE database was used to evaluate retinal vessel segmentation algorithms. It improves the analysis of vascular features such as length, width, tortuosity and branching angles. The dataset includes 40 color images from a Dutch screening program with both diabetic retinopathy and healthy subjects divided into training and testing sets. This study used 25 randomly selected images, from both groups. Due to the distinctiveness of retinal vascular structures, the database also supports multimodal image registration (**Figure – 1**) [8].

### Image preprocessing

Histogram equalization is a contrast enhancement method that redistributes pixel intensity values to improve the image. Contrast limited adaptive histogram equalization, a refined version, uses this adjustment while limiting contrast amplification to prevent noise or artifacts in image. It is especially useful in medical imaging for highlighting small retinal vessels [9].

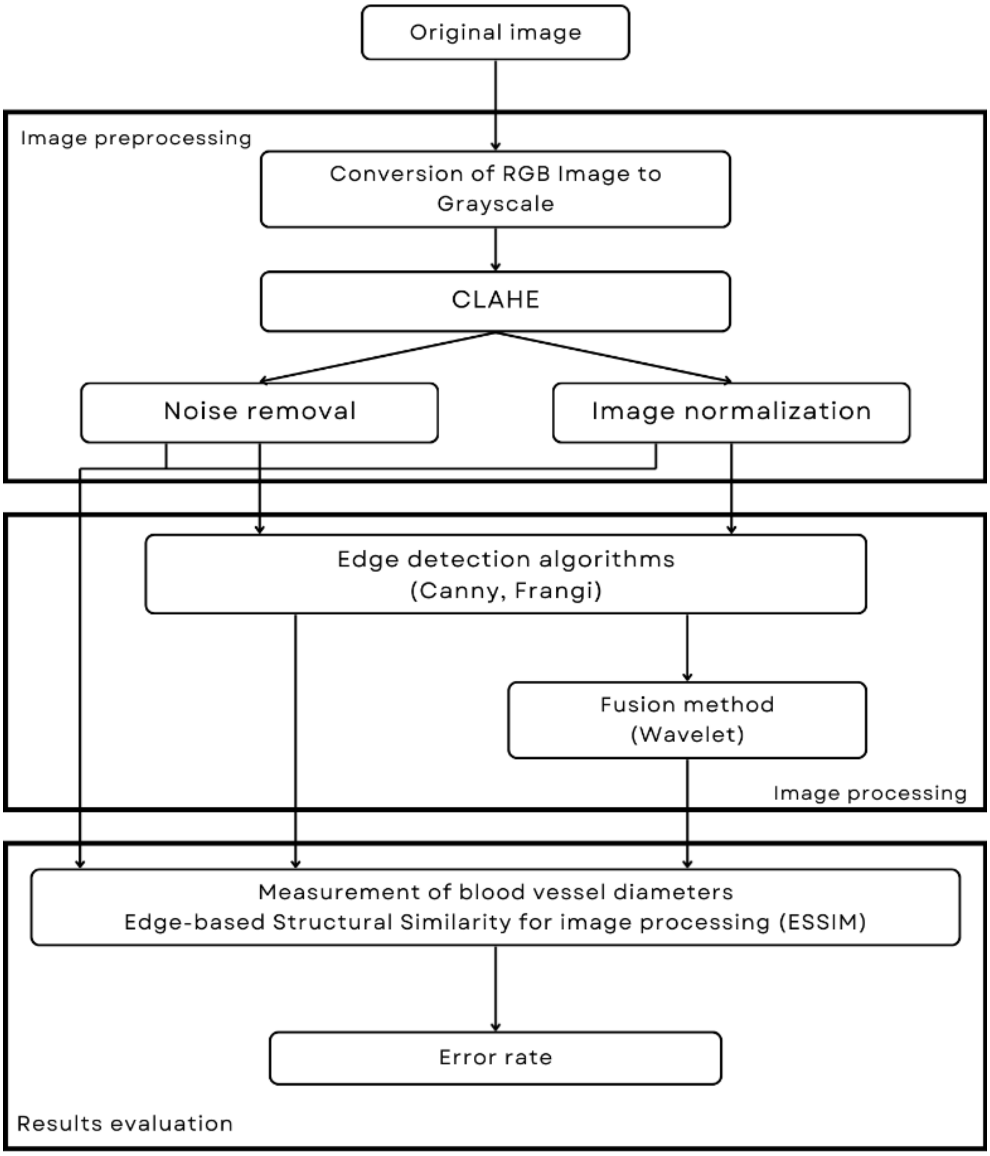
Image normalization standardizes the intensity values of pixels to a defined range, facilitating consistent visual analysis and enhancing contrast. This is done using functions like imadjust, imhistmatch or simple pixel rescaling to enhance image interpretability in clinical and technical contexts [10].

Noise reduction is an important step in improving image quality and support accurate analysis. Common denoising methods include Gaussian, median or average filtering. Each one of these methods has to suppress random variations while preserving structural details. Matlab provides adaptable tools for using these filters based on image characteristics. Furthermore, noise removal enhances segmentation precision and measurement reliability, particularly in medical imaging, where diagnostic accuracy depends on image clarity [11].

### Image processing algorithms

Canny algorithm is an accurate edge detection method known for its precision and ability to generate thin, continuous edges while effectively reducing noise. It works using Gaussian filtering to suppress high-frequency noise, gradient computation for real edge localization, non-maximum suppression and dual-threshold hysteres is to retain true edges and eliminate false positives. Because of its precision, Canny is commonly applied in medical imaging, shape recognition, and computer vision where high accuracy is essential [12].

**<u>Figure – 1</u>:** Flowchart of the proposed method implemented in MATLAB.




Furthermore, the Frangi filter is a specialized method designed to detect and enhance tubular structures such as blood vessels and nerve fibers. Frangi analyzes the eigen values and eigen vectors of the Hessian matrix, derived from second-order image derivatives, to characterize curvature and intensity orientation. Also, it is using multi-scale, directional filters, it highlights elongated and branched shapes typical of vascular tree. Sensitivity can be fine-tuned to image characteristics, making Frangi a viable technique in retinal imaging, angiography, and neuroscience applications [13-15].

**Wavelet fusion based edge detection**

Wavelet fusion method is based on discrete wavelet transform (DWT) that is used for the efficient combination of two images, providing a comprehensive representation in both spatial and frequency domains. This technique is making a decomposition of the source images through a two-dimensional wavelet transform, resulting in approximation coefficients (low-pass) and detail coefficients (high-pass) in the horizontal, vertical, and diagonal directions. Moreover, the high-pass filter enhances components such as edges or abrupt intensity variations, playing an important role in improving local contrast [16]. Also, the kernel is designed to amplify the central pixel value relative to its neighbors by employing a matrix with negative surrounding values and a central positive value. The low-pass filter is used for image smoothing and reducing intensity variations while preserving the global shapes and uniform backgrounds. After applying these filters, the results are fused using averaging techniques and the output image is reconstructed through inverse wavelet transform. The resulted image has well-defined structural details, improved contrast and reduced noise, ideal for high-precision medical diagnostics [16-18].

**Statistical Analysis**

Statistical analysis is important for evaluating the performance of image processing methods. Edge strength similarity based image quality metric (ESSIM) is a structural comparison metric used to quantify the level of similarity between two images, focused on edge features with significant intensity transitions [19]. The method consists of three steps: detecting edges in both images, comparing the vascular maps and calculating a similarity score (which reflects how the structural features are preserved during processing). ESSIM is especially valuable in applications such as segmentation evaluation, object recognition and image quality assessment, where accurate edge detection is crucial [19, 20].

The mean percentage error expresses the average percentage deviation between ground truth image values and actual values from processed images. A lower value indicate higher accuracy, making it a key metric for validating imaging-based models [21].

## Results and Discussion

In Matlab the following workflow was implemented: RGB-to-gray scale conversion, CLAHE followed by noise reduction and intensity normalization, in parallel. In the next phase, Canny and Frangi methods were used, followed by wavelet-based image fusion to generate final outputs. The final step consisted of measuring blood vessel diameters and evaluating the accuracy using ESSIM and mean percentage error. The research used 30 medical images from both diabetic retinopathy patients and healthy subjects.

All images were preprocessed and processed according to the workflow to enhance edges, reduce noise and clear artifacts. The dataset includes original, preprocessed, processed and fused images from both a pathological and control case.

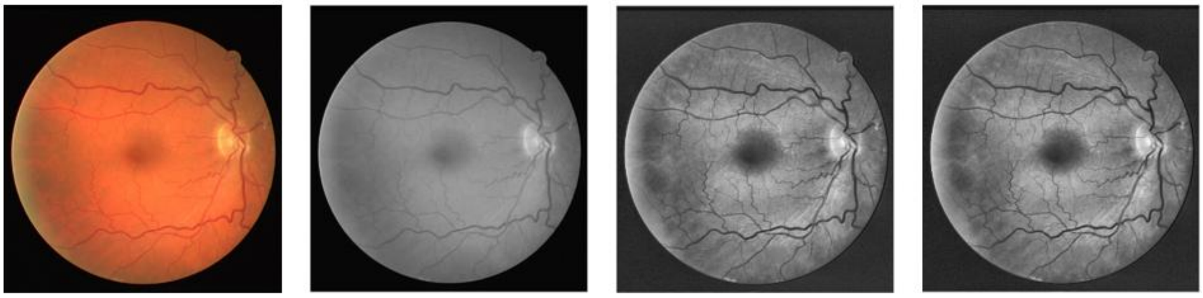
**Figure - 2** presents the operation of a preprocessing algorithm, structured into three successive steps: conversion RGB to gray scale, contrast enhancement and generation of the final processed image using Frangi and Canny algorithms. The method operates sequentially, in order to highlight relevant vascular tree features and improve the quality for subsequent processing. This method enables standardized preprocessing and ensures consistency of results in image analysis.

**Figure - 3** illustrates the edge detection steps applied to retinal images from a healthy subject (top row) and a diabetic retinopathy patient (bottom row).

In the top row, images (b) and (c) were processed using the Canny edge detection algorithm applied over images generated using normalization and noise reduction, while (d) and (e) used the Frangi filter, applied over the images resulted using the same two preprocessing algorithms. Both methods highlight vascular structures, Canny generates sharper edge localization and Frangi detects elongated tubular shapes, typical of blood vessels.

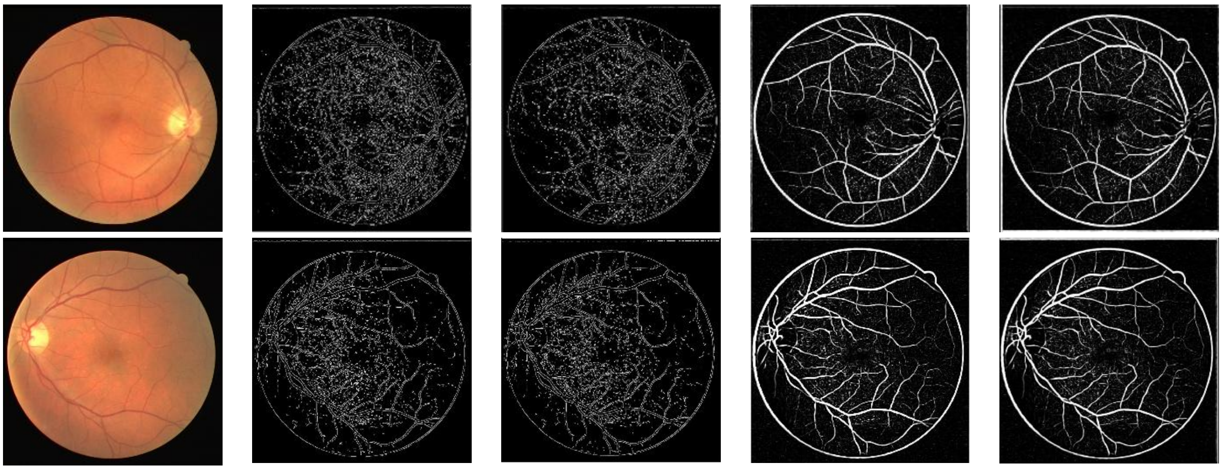
The second row uses the same sequence applied over images from a patient with diabetic retinopathy. Preprocessing highlighted pathological changes such as abnormal vessel branching or tortuosity, helping in the detection of specific features. The application of normalization and noise reduction is influencing the accuracy of both edge detection algorithms, highlighting how preprocessing affect vascular map diagnostic accuracy. These findings reinforce the importance of tailored preprocessing for optimizing the segmentation and analysis of retinal vasculature in both healthy and pathological contexts.

**Figure – 2:** Illustration of the preprocessing algorithm steps: healthy subject (top), diabetic retinopathy case (bottom). (a) original image; (b) gray scale image; (c) CLAHE; (d) final preprocessed image.



(a) (b) (c) (d)

**Figure – 3:** Examples of preprocessed images from a healthy subject (top) and a patient with diabetic retinopathy (bottom): (a) original image; Canny method: (b) normalization; (c) noise reduction. Frangi method: (d) normalization; (e) noise reduction.

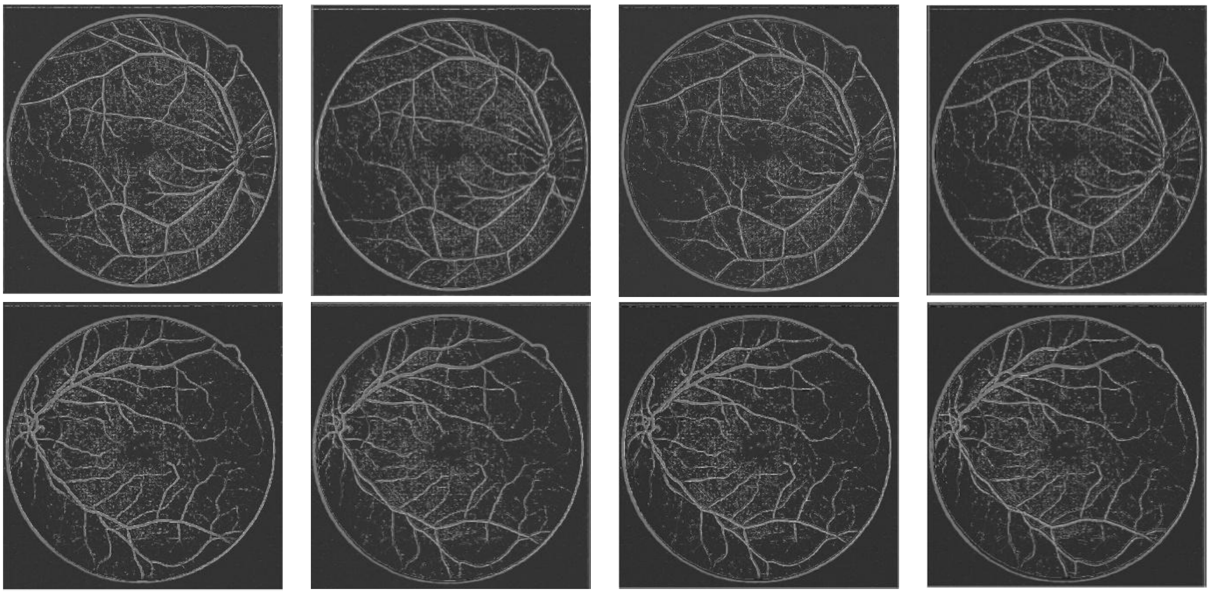


(a) (b) (c) (d) (e)

**Figure - 4**, in the upper row, illustrates vascular maps of healthy subject, obtained by applying an image fusion algorithm to various combinations of preprocessing techniques, including normalization and noise reduction, in conjunction with Canny and Frangi edge detection methods. These combinations significantly influence the quality of the results, producing variations in the clarity and level of detail of the vascular network. Each preprocessing and processing sequences offers specific advantages, contributing differently to the enhancement relevant vascular structures, particularly in the case of diabetic retinopathy. The second row presents vascular maps for a patient with diabetic retinopathy, using the image fusion algorithm applied to diverse combinations of preprocessing and processing methods, more specifically, normalization and noise reduction, used together with Canny and Frangi methods. The results are particularly valuable for morphological analysis and accurate diagnostic processes.

In the current research, several acronyms are used to simplify notation. CN and CRZ refer to the application of the Canny method to normalized and denoised images, respectively, while FN and FRZ is the Frangi filter applied over the same preprocessing results. Wavelet-based fusion algorithms are indicated as follows: CN-FN, CN-FRZ, CRZ-FN and CRZ-FRZ, representing combinations of Canny and Frangi methods applied to various preprocessing outputs. These notations provide a consistent and concise reference framework throughout the analysis.

**Figure – 4:** Vascular maps of a healthy subject (top) and a patient with diabetic retinopathy (bottom), generated using the image fusion algorithm. (a) Canny (normalization) – Frangi (normalization); (b) Canny (normalization) – Frangi (noise reduction); (c) Canny (noise reduction) – Frangi (normalization); (d) Canny (noise reduction) – Frangi (noise reduction).



(a) (b) (c) (d)

**Table – 1:** Average Vessel Diameter Values and Mean Error Rate in MATLAB.

| | **Large Vessel** | | **Thin Vessel** | | **Vessel in High Illumination Area** | |
|---|---|---|---|---|---|---|
| **Name** | **Mean Value** | **Percentage Error** | **Mean Value** | **Percentage Error** | **Mean Value** | **Percentage Error** |
| Ground truth | 607,2 | - | 594,8 | - | 582,0 | - |
| CN | 586,7 | 3,382 | 590,5 | 0,510 | 581,1 | 0,241 |
| CRZ | 640,3 | 5,444 | 609,5 | 2,6945 | 620,4 | 6,529 |
| FN | 714,1 | 17,621 | 584,8 | 1,694 | 593,2 | 1,891 |
| FRZ | 629,8 | 3,558 | 667.0 | 12,157 | 608,5 | 4,477 |
| CN-FN | 679,6 | 11,923 | 595,6 | 0,304 | 625,8 | 7,398 |
| CN-FRZ | 598,4 | 1,459 | 657,9 | 10,778 | 576,9 | 0,972 |
| CRZ-FN | 644,7 | 6,192 | 627,7 | 5,692 | 640,5 | 9,897 |
| CRZ-FRZ | 609,7 | 0,396 | 652,4 | 9,701 | 576,7 | 0,965 |

**Table – 2:** ESSIM values for the processed images.

| | ESSIM | |
|---|---|---|
| **Name** | **Mean Value** | **Percentage Error** |
| CN | 0.985 | 98,60% |
| CRZ | 0.986 | 98,62% |
| FN | 0.983 | 98,39% |
| FRZ | 0.984 | 98,44% |
| CN-FN | 0.987 | 98,77% |
| CN-FRZ | 0.987 | 98,75% |
| CRZ-FN | 0.988 | 98,87% |
| CRZ-FRZ | 0.988 | 98,85% |

According to the retinal vessel diameter values presented in **Table - 1**, the highest accuracy in determining large-caliber vessel diameters was achieved by applying the wavelet fusion algorithm to images generated from the combination of the Canny method applied to noise-reduced images and the Frangi method applied to the same image variant (CRZ-FRZ), resulting in a percentage error of only 0.396%. Furthermore, the lowest accuracy was gernerated when applying the Frangi method to normalized images (FN), which resulted in an error of 17.621%. For smaller vessels, the best results were obtained by applying the wavelet fusion to images generated by Canny and Frangi methodsapplied over normalized images (CN-FN), with errors of 0.304%, and using the Canny method on the normalized image (CN), which produced an 0.510% error. The lowest accuracy wasgeneratedby the FRZfusion, with an error of 12.157%. Additionally, for high illuminationareas, the most accurate values for the blood vessels diameter were obtained with CRZ-FRZ fusion and CN-FRZ fusion, both generating the same error of 0.965%.

**Table - 2** contains the values of the ESSIM index values for the processed images. An analysis of the values from reveals a high structural similarity between the ground truth images and the processed and fused images, all showing values above 0.95, that shows a low percentage deviation, with errors below 5%. Also, an examination of the values shows that the highest ESSM values is achieved when applying the CRZ-FN fusion, thereby confirming the effectiveness of this method in preserving the relevant features of the medical images.

## Conclusion

After ther etinal images processing, relevant results were obtained that help the diagnosis of diabetic retinopathy. The algorithms used, enabled accurate analysis of the retinal blood vessels, highlighting the efficiency of the Canny algorithm in detecting edges. Blood vessels diameter measurements were performed and the analysis showed notable accuracy for both Canny and Frangi methods. Furthermore, the application of the wavelet fusion showed better accuracy compared to individual classical methods, delivering segmented images that were less affected by illumination variations or noise. Thus, the integrated approach of this study proved to be the most suitable for clearly delineating vascular edges and supporting early diagnosis of diabetic retinopathy.

## References


1. K. Jain. Fundamentals of Digital ImageProcessing. Prentice-Hall, 1989.
2. D. Marrand E. Hildreth. Theory of EdgeDetection. Proceedings of the Royal Society of London. Series B, Biological Sciences, 1980; 207(1167): 187-217.
3. K. K. Delibasis, et al., Automatic model-based tracing algorithm for vessel segmentation and diameter estimation. IEEE Transactions on Biomedical Engineering, 2002; 49(7): 704-713.

4. Hanan Saleh S. Ahmed, J. Nordin. Improving Diagnostic Viewing of Medical Images using Enhancement Algorithms. Journal of Computer Science, 2011; 7(12): 1831-1838.
5. Fielding S. Segmentation and Focus. Digital Video Processing for Engineers, 2013; 181–190. doi:10.1016/b978-0-12-415760-6.00019-2
6. N. Otsu. A Threshold Selection Method from Gray-Level Histograms. IEEE Transactions on Systems, Man, and Cybernetics, 1979; 9(1): 62-66. doi: 10.1109/TSMC.1979.4310076.
7. Acharya și Ray. Image Processing Principles and Applications. Wiley-Interscience, 2005. ISBN 0-471-71998-6
8. Image Science Institute, University Medical Center Utrecht. Available from: http://www.isi.uu.nl/Research/Databases/DRIVE/
9. Haddadi Y.R., Mansouri B., Khodja F.Z.I. A novel medical image enhancement algorithm based on CLAHE and pelican optimization. Multimed Tools Appl, 2024. https://doi.org/10.1007/s11042-024-19070-6
10. Parker J. R. Algorithms for Image Processing and Computer Vision, 2010, 2nd edition, Wiley.
11. Rudin L. I., Osher S., Fatemi E. Non linear total variation based noise removal algorithms. Physica D: Non linear Phenomena, 1992; 60(1-4): 259-268.
12. J. Canny. A Computational Approach to Edge Detection. IEEE Transactions on Pattern Analysis and Machine Intelligence, 1986; PAMI-8(6): 679-698.
13. Frangi A. F., Niessen W. J., Vincken K. L., Viergever M. A. Multiscale vessel enhancement filtering. In Medical Image Computing and Computer-Assisted Intervention - MICCAI'98. Springer, Berlin, Heidelberg, 1998; pp. 130-137.
14. Shi J., Malik J. Normalized cuts and image segmentation. IEEE Transactions on Pattern Analysis and Machine Intelligence, 2000; 22(8): 888-905.
15. Pham D. L., Xu C., Prince J. L. Current methods in medical image segmentation. Annual Review of Biomedical Engineering, 2000; 2: 315-337.
16. Obreja C. D., Moraru L. Retinal vascular system edge detection based on wavelet image fusion and first order derivative algorithms. International Multidisciplinary Scientific Geo Conference: SGEM, 2019; 19(6.3): 189-196.
17. Li C., Xu C., Gui C., Fox M. D. (2005). Level set evolution without re-initialization: A new variational formulation. Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition, 2005; pp. 430-436.
18. Klein S., Staring M., Murphy K., Viergever M. A., Pluim J. P. W. elastix: A toolbox for intensity-based medical image registration. IEEE Transactions on Medical Imaging, 2010; 29(1): 196-205.
19. S. Betrabet, C.K. Bhogayta. Structural Similarity based Image Quality Assessment using full reference method. International Journal of Scientific Engineering and Technology, 2015; 4(4): 252- 255.
20. Cheng J., Wang Z. Improved structural similarity index for image quality assessment. Journal of Computer Science, 2014; 10(2): 353-360.
21. Tofallis, Chris, Measuring Relative Accuracy: A Better Alternative to Mean Absolute Percentage Error. Hertfordshire Business School Working Paper, 2013. http://dx.doi.org/10.2139/ssrn.2350688