AUTOMATIC EXTRACTION OF RETINAL BLOOD VESSELS: A SOFTWARE IMPLEMENTATION

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Abstract

In the field of sports injuries, the injuries are often classified as traumatic or overuse injury. Also, high-velocity flying objects can do irreparable damage to the human eye. In traumatic head injuries, small blood vessels of athlete's eye are often damaged, also these vessels may produce bleeding within the front chamber of the eye, between the iris and cornea (e.g., Hyphema). In the scope of image processing, segmentation of the optic disc, blood vessels and macula in digital fundus images is important for the research area of medical image analysis. It is used to efficiently implement the diagnostic evaluation and taken as a basis of the cure to illness of patient. Automatic segmentation of retinal blood vessels is a preliminary step in the development of a computer-assisted diagnostic system for ophthalmic problems. The Sobel and Prewitt edge detectors are based on the discrete differentiation operators. The Kirsch compass kernel is a non-linear edge detector. These edge detectors usually find the maximum edge strength in predetermined directions. SCILAB is an open source, cross-platform numerical computational package. It uses a high-level, numerically oriented programming language that it is similar to MATLAB numerical computing environment. In this paper, the Sobel, Prewitt edge detectors and the edge detection based on the Kirsch templates (i.e., kernel) are used to detect and extract the retinal blood vessels by using developed SCILAB implementation. Considering the computer science in sport research area, the proposed approach given in this study aims to show an open source and efficient implementation of automatic blood vessel extraction, and comparison of the performance of three different edge detectors. In the experiments, the DRIVE retinal image database is used to test the developed approach. Experimental results show that our implementation based on Kirsch templates is more preferable than standard implementations of Sobel and Prewitt edge detectors used in SCILAB's image processing design (IPD) and image and video processing (SIVP) toolboxes.

Keywords : Retinal blood vessels, Kirsch template, Sobel, Prewitt, DRIVE, SCILAB

Introduction

The sports-players are at particular risk on the sport field. The sports-related, recreational activities and eye injuries are extremely painful and destructive that high-velocity flying objects can do irreparable damage to the human eye. Considering the speed on the field, professional baseball players throw balls at about 95 mph, an average hockey puck travels at 90-100 mph, the elite squash players strike the ball at 125-145 mph, also a badminton shuttlecock has been traveled at 140 mph (Will's Eye Institute Webpage, 2012). The Hyphema is an example issue on the eye injuries. It is bleeding within the front chamber of the eye, between the iris and cornea. This is usually caused by a direct impact to the eye from a blunt object. Also, it is usually caused by punches to eye, falls or being hit with a ball or other flying object (Sports Injury Clinic Webpage, 2012).

In the scope of image processing, segmentation of the optic disc, blood vessels and macula in digital fundus images is important for the research area of medical image analysis. It is used to efficiently implement the diagnostic evaluation and taken as a basis of the cure to illness of patient. Early diagnostic is play an important vital role and prevent various cardiovascular and ophthalmologic diseases/problems. Generally, these problems are diabetes, cardiovascular disease, hypertension, arteriosclerosis, chorodial neovascularization, injuries and etc.

Automatic segmentation of retinal blood vessels is an essential step in the development of a computer-assisted diagnostic system for ophthalmic problems. For extracting of human eye vasculature from every medical image modality, the segmentation methods vary depending on the imaging modality, application domain method being automatic or semi-automatic and other specific factors, also there is no single segmentation method in the literature (Vijayakumari and Suriyanarayanan, 2012). The image quality and artifacts are important issues that they may cause under- or over-segmentation problems. The morphological operators can be used simply to detect contours of retinal blood vessels, but this operation is not sufficient to extract the exact body of all blood vessel structure. Therefore, blood vessel extraction is an important tool to obtain the desired information. The edges of typical image characterize object boundaries and are therefore useful for segmentation, registration, and identification of objects in a given scene. An edge is defined by a discontinuity in gray level values. Therefore, an given edge is the boundary between an object and the background of given scene (i.e., between two regions).

Gradient edge detectors (i.e., First derivative or Classical) use differentiation operators. Image gradients are the directional changes in the intensity or color in an given image that it is used to extract useful information from the image. Edge detection is an active research area as it facilities higher level image analysis (Vijayakumari and Suriyanarayanan, 2012; Maitra et al., 2012). Kirsch operator or compass kernel (Gao et al., 2010) is an edge detection filter technique. In the literature, there are a lot of edge detection filters, such as Sobel, Prewitt, Marr-Hildereth, Roberts, Robinson, Kirsch and etc. Some classical edge detectors used in this study are also reviewed at Section 3, such as Sobel, Prewitt and Kirsch which use 2D gradient vector with the components given by the derivatives in the horizontal and vertical directions. At each image point, this vector indicates the direction of possible intensity increase (Maitra et al., 2012).

SCILAB is an open source, cross-platform numerical computational package. It uses a high-level, numerically oriented programming language that it is similar to MATLAB numerical computing environment (SCILAB webpage, 2012). I have compared the results obtained by the proposed approach with other known methods of edge detection, i.e., Sobel and Prewitt edge detection filters. The comparison is made by using SCILAB implementations of Sobel, Prewitt filters and the proposed approach. The objective of the process given in this study is to find the specification of the medical image and assess the performance of given edge detector in a qualitative way.

This paper is organized as follow. Section 2 describes the related work of edge detection research area where the classical edge detection filters have been discussed, and reviews the retinal blood vessel detection and/or segmentation (and extraction) studies in the literature. In Section 3 the related methods and developed approach in this study are discussed. Section 4 provides the comparative results of given experiments of this study. Finally, Section 5 concludes the paper.

Related work

In the literature, a lot of studies are focused on the detection and segmentation of retinal blood vessels. The edge detection is an essential tool for image segmentation. Segmentation divides an image into its component parts or objects. These object(s) are generally the object(s) of interest for a given application. Segmentation algorithms interest the discontinuity or similarity of image intensity or color values which are presented by given image. The approach of discontinuity is to partition given image based on the abrupt (i.e., inter-regions) changes or gradual changes (i.e., intra-region) in the intensity or color values. The approach of similarity is to partition given image based on predefined criteria which are based on image features or some metrics. According to Muthukrishnan and Radha (2011), the classical methods of edge detection operates on convolving the image through an operator. This operator is constructed to be perceptive to large gradients in the image. Yin et al. (2012) discussed about vessel structures such as retinal vasculature are important features for computer-aided diagnosis. They are proposed a probabilistic tracking method to detect blood vessels in retinal images. According to Yin et al., most of the work on vessel segmentation can be categorized into two main groups: pixel-based methods and tracking methods. Also, techniques used for identifying vessels are based on matched filters, morphological filters, fuzzy c-means classifiers, or the optimization of Gaussian profiles (Yin et al., 2012).

Saleh and Eswaran (2012) proposed an algorithm that it takes advantage of powerful image processing techniques such as contrast enhancement, filtration and thresholding for more efficient segmentation. In their study, the experiments were conducted on 40 images collected from DRIVE database (Niemeijer and van Ginneken, 2002). Their experimental results show that the proposed algorithm yields a higher accuracy rate for segmentation. Saleh and Eswaran (2012) categorized a number of approaches for automated blood vessel segmentation into four main group: pattern recognition techniques, model-based approaches, tracking-based approaches and artificial intelligence-based approaches (e.g., neural networks). Yang et al. (2008) discussed about blood vessel information such as length, width, tortuosity and branching pattern. These features can not only provide information on pathological patterns. They can frequently help to grade diseases severity or automatically diagnose the diseases. According to Yang et al. (2008), manual detection of blood vessels is much more difficult task since the blood vessels in a retinal image that they are complex and with low contrast. To judge a disease, there are also a number of retinal images (e.g., DRIVE database). In their study, Yang et al. (2008) presented a novel hybrid automatic approach for the extraction of retinal image vessels. The method consists in the application of mathematical morphology and a fuzzy clustering algorithm followed by a purification procedure.

According to Zhang et al. (2010), matched filter is a simple yet effective method for vessel extraction. In addition, a matched filter will respond not only to vessels but also non-vessel edges which will lead to false vessel detection. Zhang et al. proposed a novel extension to the matched filter approach to detect retinal blood vessel. Their proposed method reduces significantly the false detections produced by the original matched filter. Also, it detects many fine vessels. Esmaeili et al. (2009) presented an efficient method for automatic extraction of blood vessels in retinal images to improve the detection of low contrast and narrow vessels. Their proposed algorithm is composed of four steps: curvelet-based contrast enhancement, match filtering, curvelet-based edge extraction, and length filtering. In their study, after reconstruction of enhanced image from the modified curvelet coefficients, match filtering is used to intensify the blood vessels. Also, the curvelet transform is employed to segment vessels from its background. In addition, the length filtering is used to remove the misclassified pixels. Their experimental results are evaluated on DRIVE database (Niemeijer and van Ginneken, 2002).

In Section 3, some edge detection methods used in this study are reviewed. In addition, Section 3 describes the details of the proposed approach and its implementation on the SCILAB environment (SCILAB webpage, 2012).

Methods and Developed Approach

In the literature, there are a lot of gradient edge detectors. In the study of Maitra et al. (2012), they classified these detectors with respect to the differentiation operators. The most commonly used discontinuity based edge detection techniques are Sobel, Prewitt and Kirsch edge detection. In related subsections, these techniques are given as the classical (i.e., first derivative) edge detectors used in this study.

Sobel edge detection

The Sobel filter is a discrete differentiation operator. It is computing an approximation of the gradient of the image intensity function (Maitra et al., 2012). For image segmentation, Sobel method finds edges using the Sobel approximation to the derivative. Therefore, it precedes the edges at related points where the gradient is highest (Muthukrishnan and Radha, 2011). The result of Sobel operator at each point in the image is either the corresponding gradient vector or the norm of the gradient vector. In horizontal and vertical direction, it is based on convolving the image with a small, separable, and integer valued filter, and performs a 2-dimensional spatial gradient quantity on given image (Maitra et al., 2012; Muthukrishnan and Radha, 2011). The Sobel operator uses two 3x3 complication kernels. They are convolved with the given original image to calculate approximations of derivatives. In addition, S_x and S_y are two images which at each point contain the horizontal and vertical derivative approximations. Also, one kernel is simply the other rotated 90 degrees. For a given source image I_1, the computations are given as follows (Maitra et al., 2012; Muthukrishnan and Radha, 2011):

$$S_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} * I_1 \quad and \quad S_y = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix} * I_1 \qquad (1)$$

In Eq. (1), (*) operator denotes the 2-dimensional convolution operation. The gradient magnitude is given as below (Maitra et al., 2012):

$$G = \sqrt{S_x^2 + S_y^2} \tag{2}$$

The Sobel kernels can be thought of as 3x3 approximations to first-derivative of Gaussian kernels.

Prewitt edge detection

The Prewitt filter is a discrete differentiation operator. It is a correct way to estimate the magnitude and orientation of an edge in given image. Prewitt edge detection is simpler to implement computationally than Sobel edge detection (Muthukrishnan and Radha, 2011). According to Muthukrishnan and Radha (2011), the compass edge detection obtains the direction directly from the kernel with highest response. The gradient edge detection of Prewitt is limited to eight possible directions. The operator uses two 3x3 kernels. Also, the edge detection is estimated in these 3x3 neighborhood for eight directions. The kernels of Prewitt are convolved with the original image to calculate approximations of the derivatives (Maitra et al., 2012; Muthukrishnan and Radha, 2011). In addition, P_x and P_y are two images which at each point contain the horizontal and vertical derivative approximations. For a given source image I_2, the computations are given as follows (Maitra et al., 2012; Muthukrishnan and Radha, 2011):

$$P_x = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix} * I_2 \quad and \quad P_y = \begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix} * I_2 \tag{3}$$

Also, (*) operator in Eq. (3) denotes the 2-dimensional convolution operation. In addition, these kernels are sensitive to noise.

Kirsch edge detection

For Kirsch edge detection, the edge image (i.e., detected edges) can be regarded as the space gradient. The Kirsch operator can adjust the related threshold value automatically due to the image characteristics. Therefore, the Kirsch gradient operator is chosen to extract the contour of the object(s) (Gao et al., 2010). The Kirsch edge detection uses eight filters (i.e., eight masks for related eight main directions) that are applied to given image to detect edges (Maitra et al., 2012; Muthukrishnan and Radha, 2011). These eight filters (i.e., window templates) are a rotation of a basic 3x3 compass convolution filter (i.e., a single mask). These directions are North, Northwest, West, Southwest, South, Southeast, East and Northeast. The masks are distinct as given below (Muthukrishnan and Radha, 2011):

$$M_0 = \begin{bmatrix} 5 & 5 & 5 \\ -3 & 0 & -3 \\ -3 & -3 & -3 \end{bmatrix}, M_1 = \begin{bmatrix} 5 & 5 & -3 \\ 5 & 0 & -3 \\ -3 & -3 & -3 \end{bmatrix}, M_2 = \begin{bmatrix} 5 & -3 & -3 \\ 5 & 0 & -3 \\ 5 & -3 & -3 \end{bmatrix} \tag{4}$$

$$M_3 = \begin{bmatrix} -3 & -3 & -3 \\ 5 & 0 & -3 \\ 5 & 5 & -3 \end{bmatrix},\ M_4 = \begin{bmatrix} -3 & -3 & -3 \\ -3 & 0 & -3 \\ 5 & 5 & 5 \end{bmatrix},\ M_5 = \begin{bmatrix} -3 & -3 & -3 \\ -3 & 0 & 5 \\ -3 & 5 & 5 \end{bmatrix} \tag{5}$$

$$M_6 = \begin{bmatrix} -3 & -3 & 5 \\ -3 & 0 & 5 \\ -3 & -3 & 5 \end{bmatrix},\ M_7 = \begin{bmatrix} -3 & 5 & 5 \\ -3 & 0 & 5 \\ -3 & -3 & -3 \end{bmatrix} \tag{6}$$

Except the outermost row and the outermost column, every pixel and its eight neighborhoods in a given image are convolved with these eight templates, respectively. Every pixel has eight outputs. Also, the maximum output of the eight templates is chosen to be the value in given position (Gao et al., 2010). This is defined as the edge magnitude (Muthukrishnan and Radha, 2011). A point's gray value with its eight neighborhoods are given in Fig. 1.

P_0	P_1	P_2
P_7	$P(i,j)$	P_3
P_6	P_5	P_4

Figure 1: A point's gray value with its eight neighborhoods.

The direction of edge is defined by the related mask that produces the maximum magnitude (Muthukrishnan and Radha, 2011).

Developed approach

In this study, a SCILAB implementation is realized to extract the retinal blood vessels using each one of edge detectors such as Sobel, Prewitt and Kirsch. For color retinal images, the image segmentation based on the detection of edge(s) in given image is done in three phase. In first phase, a given test image is loaded into the SCILAB system's workplace as a three-channel color *RGB* image. Proposed segmentation system convert this image into a *grayscale*-tone image. In second phase, the proposed system proceed the related edge detection mechanism for each one of abovementioned methods. In addition, the proposed system starts by checking intensity values from the image data at second phase. These data are scanned by horizontally from leftmost pixel of a row of a two dimensional pixel array to the rightmost pixel of the same row. Also, the proposed system considers one row of image data at a time. However, it iterates after completing the operations to next row, then it continues until the last row is processed.

In third phase, the same process is repeated in the vertical direction by considering a column-wise scanning. In second and third phase, if necessary for a given method, the proposed system checks the filtered result of (operational) gray value at given point is greater than a given threshold, then it apply this value to the edge image. At the end of the third phase, the proposed system shows the resultant edge image to its end-user.

Experimental results

In this study, performance of three different template matching algorithms, namely, Sobel, Prewitt and Kirsch template-based edge detection method are analyzed for detection and segmentation of blood vessels in the color retinal images. SCILAB software has some modules and toolboxes for additional features, such as the image processing design (IPD) toolbox and the image and video processing (SIVP) toolbox. These toolboxes have "*EdgeFilter*" built-in function for IPD and "*fspecial*" (and "*filter2*") built-in function for SIVP. In our experiments, SCILAB "*v5.3.3 version*" is used to implement our approach which covers Sobel and Prewitt two-dimensional filters by abovementioned functions of SCILAB's toolboxes. In addition, we designed and implemented the Kirsch template-based edge detection for comparison of other two methods on the SCILAB environment.

The experiments are conducted over 20 images of DRIVE database (i.e., test images), which contains a large number of ground-truth (i.e., reference) of retinal images, each of which has been hand-segmented by human observers, while the benchmark provides a methodology for quantifying segmentation performance. By the way, all comparison results are not included in this study because of page limit. Instead, to show that the proposed approach is suitable for all retinal image edge detection and segmentation, only some visual segmentation results are shown in Fig. 2 to Fig. 6, respectively. In these figures, the results are compared with each other as given column-wise.

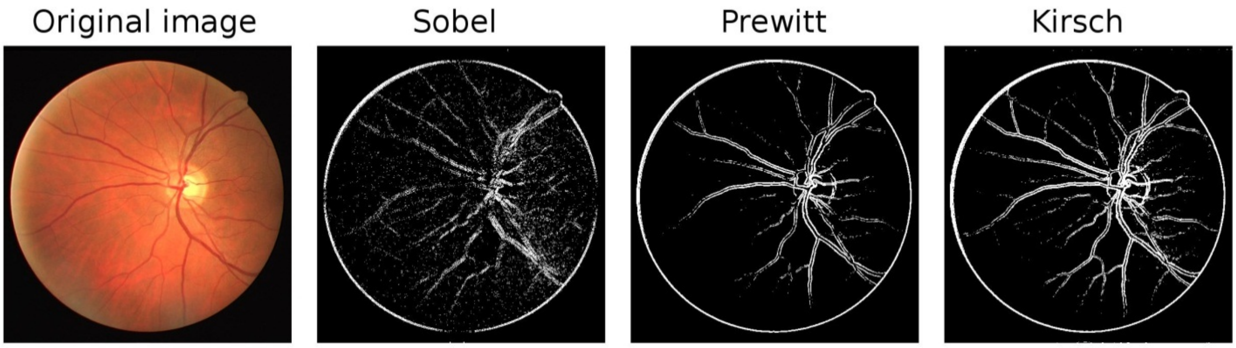

Figure 2: The qualitative performance comparison on the "*04_test*" image.

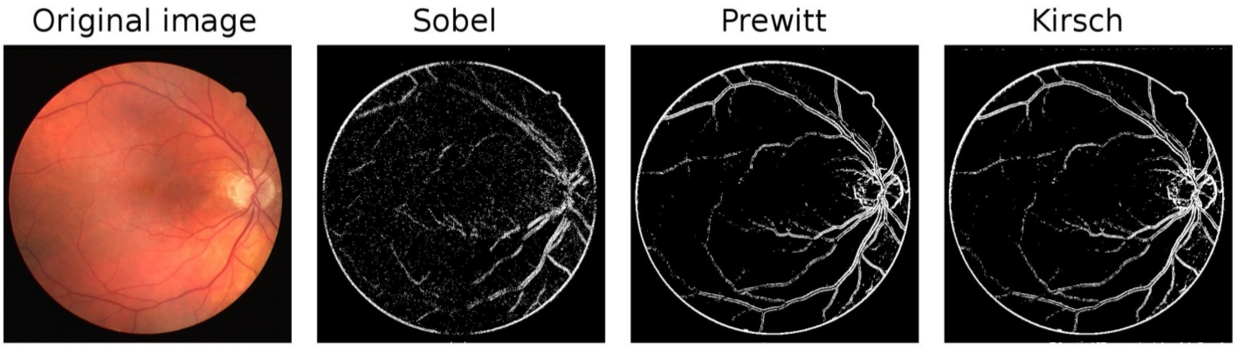

Figure 3: The qualitative performance comparison on the "*07_test*" image.

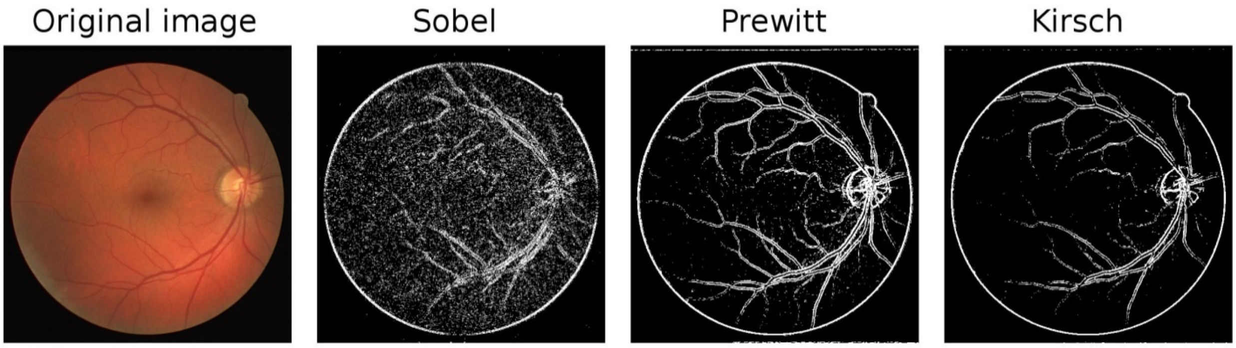

Figure 4: The qualitative performance comparison on the "*10_test*" image.

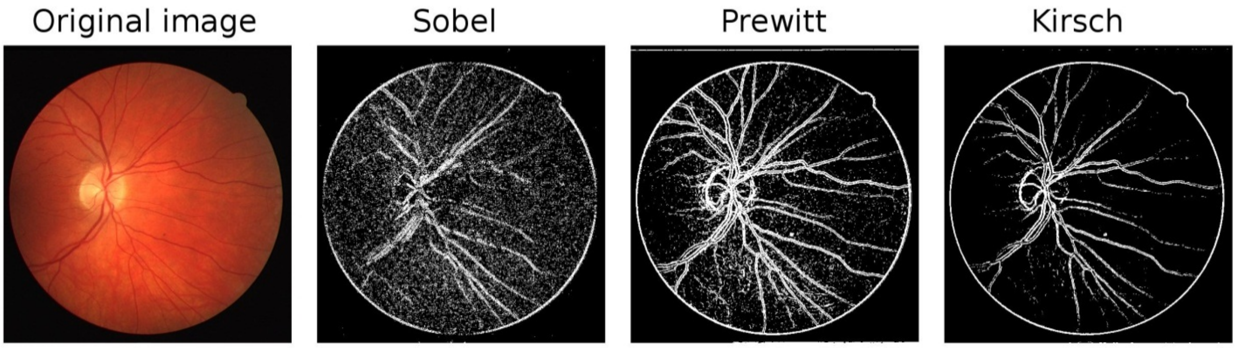

Figure 5: The qualitative performance comparison on the "*15_test*" image.

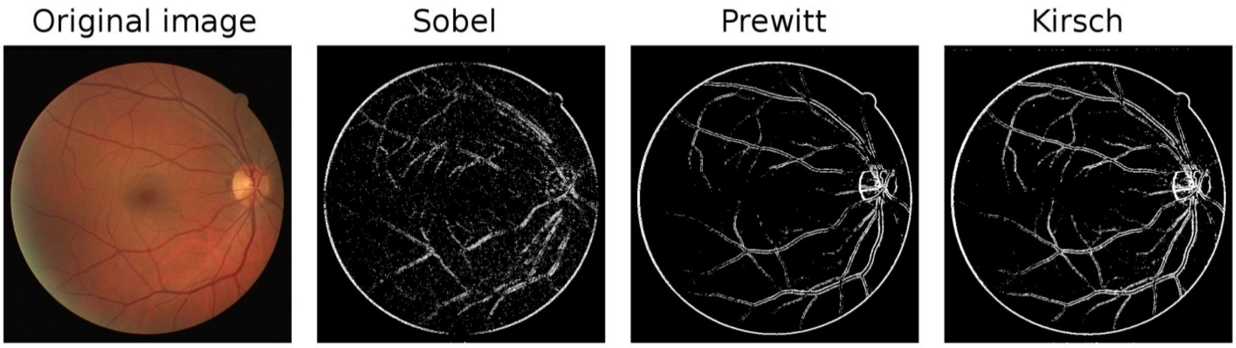

Figure 6: The qualitative performance comparison on the "*19_test*" image.

The Fig. 2 shows the qualitative performance comparison on the "*04_test*" image of DRIVE database. Also, the Fig. 3 shows the qualitative performance comparison on the "*07_test*" image of DRIVE database. The Fig. 4 shows the qualitative performance comparison on the "*10_test*" image of DRIVE database. In addition, the Fig. 5 shows the qualitative performance comparison on the "*15_test*" image of DRIVE database. The Fig. 6 shows the qualitative performance comparison on the "*19_test*" image of DRIVE database. As seen from images in these figures, the Kirsch compass templates-based edge-based segmentation is superior in some figures (i.e., "*04_test", "15_test"* and "*19_test"* images) by far to Sobel and Prewitt methods.

Conclusion

The proposed system produces three different edge maps which are based on the Sobel, Prewitt and Kirsch edge detection methods. In addition, the edge map images are relatively free from any noise. The edge-based segmentation using Kirsch compass templates is superior by far to other methods. The SCILAB is a freeware and easy to use environment by end-users. However, the SCILAB supports some two-dimensional edge filters, but does not support already Kirsch template.

In this study, the Kirsch template-based implementation is tested on retinal color images, also, its results show that it is a necessary and successful tool for edge detection and must supported by SCILAB. In this way, the diagnostic evaluation for sports-injuries will be much easier and accessible by the experts in the field.

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