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Automated Segmentation of Hard Exudates Based on Matched Filtering

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***Abstract*—In 2015, according to the International Diabetes Federation (IDF), around 415 million of people worldwide lived with diabetes and it was predicted to be increased by 642 million of people in 2040. One of the diabetes complications that affect the retina is known as diabetic retinopathy (DR). It is indicated by the presence of hard exudates as the main pathology of DR. In retinal fundus images, hard exudates appear as bright lesion which has some similar characteristics with the optic disc. This paper proposes a method to automatically detect hard exudates. At first, the green channel is extracted from the retinal colour fundus image. The complement of green channel is used to increase the contrast between hard exudates and the background. The complemented image is filtered by using matched filter. Optic disc (OD) is detected based on initial optic disc enlargement in L band of HSL colour space. Afterwards, optic disc is removed from filtered image to obtain the candidates of hard exudates followed by the morphological operation. The proposed method is validated by using 60 colour fundus images from DIARETDB1 dataset. The final results of segmented exudates are verified by comparing with their ground truth images. The average level of accuracy, sensitivity and specificity achieved are 99.99%, 90.38% and 99.99%, respectively. These results indicate that the proposed method successfully detected the hard exudates. Hence, it is recommended to be implemented as a part of DR grading system development.**

Keywords— colour fundus image; hard exudates; matched filter; morphological operation; optic disc

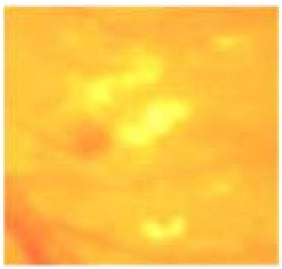
I. INTRODUCTION

Diabetes mellitus (DM) is a metabolic disease. It occurs when insulin is not able to properly produce and causes an excess of glucose in the bloodstream (hyperglycaemia). International Diabetes Federation (IDF) stated that 415 million of people worldwide lived with diabetes in 2015 and it is predicted that around 642 million people by 2040 will suffer from this disease [1].

Diabetic retinopathy (DR) is one of the complications caused by long-term effect of diabetes on the retina. This disease causes a serious damage to the eyes (blindness) due to the damage of retinal vessels. Therefore, early detection of pathologies is needed to reduce the effect on the retinal damage not only relying on visual examination but also supported by computer aided detection (CAD) [2]. Diabetic retinopathy is classified into three types, i.e. proliferative diabetic retinopathy (PDR), non-proliferative diabetic retinopathy (NPDR) and diabetic macula oedema (DME) [3]. PDR is indicated by the presence of neovascularisation, while NPDR has been indicated by the presents of some pathologies such as micro aneurysms, haemorrhages and exudates.

There are two kinds of exudates, i.e. soft exudates and hard exudates. Soft exudates are also known as cotton wool spots (CWS) and appear as whitish with unclear edges. Hard exudates occur due to the leakage of protein and lipid of retinal vessels. They appear sharply and brightly. The presence of hard exudates in macular area is known as DME. It can cause a loss of permanent vision. Two sub-types of macular oedema are non-clinically significant macular oedema (NCSME) and clinically significant macular oedema (CSME) [4]. Examples of CWS and hard exudates are depicted in Fig. 1.

(a)



(b)

Fig. 1.The characteristics of (a) Cotton wool spots and (b) Hard exudates [5]

Various image processing based approaches have been developed and reported to automatic detection hard exudates as one of the pathologies of DR using fundus images. Early diagnosis of DR by automated detection exudates and cotton wool spots based on machine learning was employed by [6]. They used 300 digital colour fundus images from a diabetic retinopathy telediagnosis database to test the proposed approach and then the result was evaluated by using annotation of two retinal experts. A hybrid fuzzy classifier was applied in [7] to detect dark lesion (micro aneurysms and haemorrhages) and bright lesion (hard exudates and cotton wool spots) in fundus photograph for early detection of DR. The proposed approach was tested on four different datasets.

Segmentation based on clustering has been conducted in [8] using the combination of thresholding and morphology to eliminate optic disc at first. Exudates detection was conducted by extracting features and selecting four relevant features from ten features, i.e. intensity, deviation standard, hue and number of edge pixels as input to FCM clustering. Some artefacts obtained from image acquisition were detected as exudates caused by their similarity.

Segmentation based on region growing was conducted in [9] using split and merge for exudates detection. At first, optic disc was eliminated using Hough transform that detected the main circular feature of circular region of interest, obtained from morphology operation. Exudates were then detected using adaptive thresholding based on optimal partitioning from split and merge algorithm.

The modification of RGB to segment hard exudates by applying Frei-Chen operator was done by [10]. The edge of segmented image here was enhanced using Kirsch's method to remove other yellow lesions. Other researcher used morphological reconstruction to automatically detect hard exudates [11]. A combination of adaptive thresholding and Gabor filter was applied in [12] to obtain exudates as a bright lesion. The high pass filtering-based was applied in [13] to detect exudates and combined with optic disc elimination to reduce false positive of exudates detection. All of the aforementioned research works aimed to assist ophthalmologists in diagnosing DR and achieve right treatment for diabetes patients.

The objective of this work is to develop automated detection of hard exudates on the colour retinal images. This paper is organised in four sections. Introduction of the background and some study literatures are explained in Section I followed by explanation of the proposed approach in Section II. In the third section describes experiment results and discussion. Finally, the conclusions are described in last section.

II. Approach

The retinal colour fundus images from DIARETDB1 dataset [5] are used as input. Ground truth images are provided in the dataset to evaluate the performance of proposed approach.

At first, green channel is extracted from input image. Afterwards, the image complement of green channel undergoes matched filtering to obtain candidate of hard exudates. Optic disc area is removed using the developed method in [13]. Morphological operation is employed to get the final hard exudates. At the last, detected hard exudates are validated to the ground truth image by measuring accuracy, sensitivity and specificity. The flowchart of the approach is presented in Fig. 2.

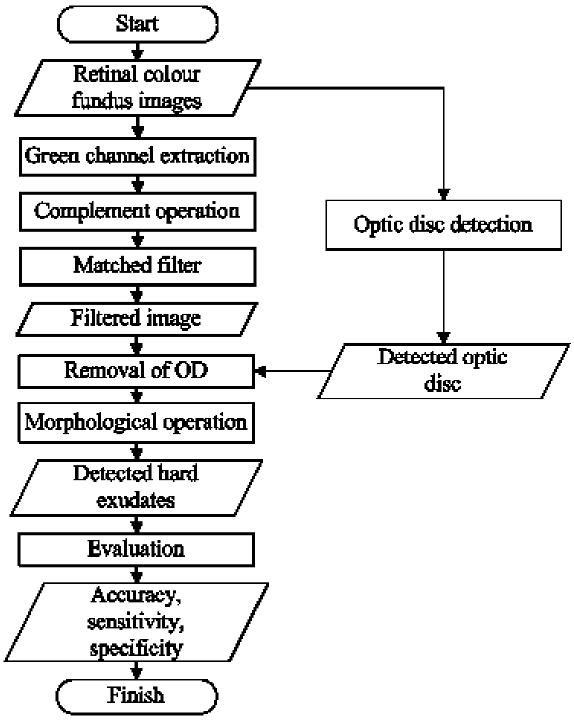


Fig. 2. Flow diagram of the proposed approach.

The green channel is extracted from original image. It is chosen because green channel contains enough information to detect hard exudates since it has the highest contrast among the others.

Afterwards, complement operation is applied to the extracted green channel. In the complement operation of binary images, black and white is reversed; zero values are replaced by ones and ones are replaced by zeros. For 8-bit RGB images, the maximum pixel value (255) is subtracted to each pixel value of input image. So, light areas become darker while dark areas become lighter in the output image.

The matched filter is employed to the complemented image for obtaining candidates of hard exudates. This work involves twelve rotated of matched filter windows adopted from [14].

The candidates of hard exudates are multiplied by segmented OD and each masking image to remove OD and the border from the image. Furthermore, morphological dilation and erosion (1) are used to obtain final hard exudates.

$$AoB = (A\Theta B) \oplus B \quad (1)$$

Evaluation process aims to measure performance of proposed approach by comparing detected hard exudates to the ground truth image. In this work, it is done by considering statistical measurement based on accuracy, sensitivity and specificity.

III. Results and Discussion

The proposed approach is tested using 60 images are taken from DIARETDB1 dataset [5]. DIARETDB1 is a publicly available dataset that provides retinal colour fundus images in PNG (RGB) format with resolution of 1500x1152 pixels. It is referred to as calibration level 1 fundus images that captured using 50 degree field of view (FoV) with several imaging setting. The available ground truth images are marked by four medical experts using a software tool to annotate fourth areas, i.e. micro aneurysms, haemorrhages, cotton wool spots (CWS) and hard exudates. Some examples of visual experts marking are illustrated in Fig. 3.

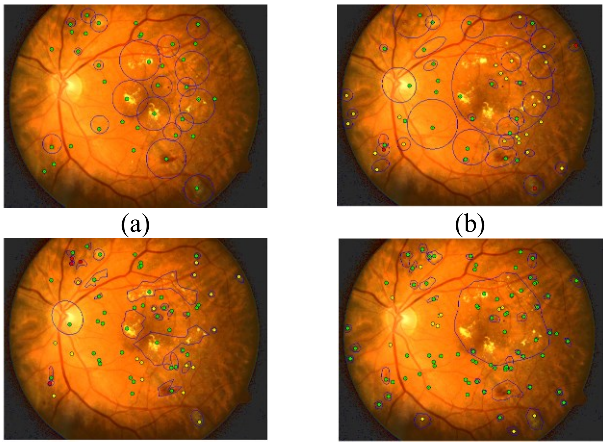


Fig. 3. Visual experts marking: (a) Expert 1 (b) Expert 2 (c) Expert 3 (d) Expert 4 [5]

A. Removal of optic disc

Removal of optic disc is conducted by using the method that has been developed in last work [13]. The RGB input image is converted to HSL colour space. L band is chosen for further process since information in others band do not enough to detect OD. Furthermore, some steps are applied to L band such as CLAHE, contrast stretching and median filtering to get initial area of optic disc. Finally, optic disc is detected based on enlargement process of initial area. Details of explanation can be seen from [13]. The result of these processes is depicted in Fig. 4.

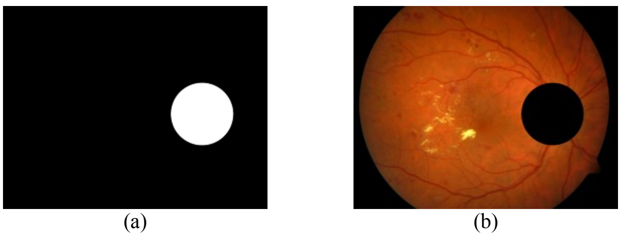


Fig.4. (a) Segmented OD (b) Removal of OD.

B. Detection of hard exudates

The original input image consists of three channels, i.e. red, green and blue channels. Extracted green channel is used for further process since some information for exudates detection is not properly contained in the red and blue channels. The red channel is so bright whilst blue one is so dark. These results are shown in Fig. 5.

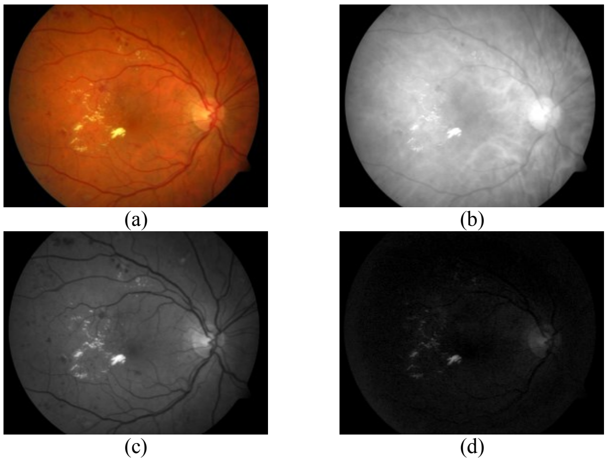


Fig. 5. The result of channels extraction: (a) Original image (b) Red channel (c) Green channel (d) Blue channel.

Extracted green channel is processed by complement operation that reserve hard exudates as bright lesion to be dark area as presented in Fig. 6. Complemented image is then filtered based on matched filtering. A total of 12 rotations matched filter window are processed to entire images. Several parameters adopted from [14] are considered in this work such as $\sigma = 2.1$, $L = 10$, $T = 10$ and $\theta = 0^{o}$ to 175^{o}. An example of matched filtering result is shown in Fig. 7 (a). Removal of optic disc and masking are then applied to the filtered image to obtain candidates of hard exudates as presented in Fig. 7 (b).

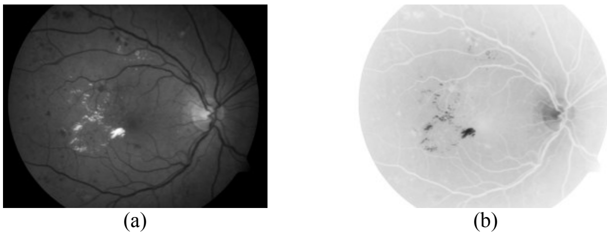


Fig. 6. (a) Extracted green channel (b) Complemented image.

Fig. 7. (a) Filtered image (b) Candidates of hard exudates.

After the candidates of hard exudates are obtained, morphological operation based on erosion and dilation is employed to reach final segmented hard exudates as shown in Fig. 8.

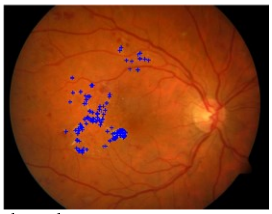


Fig. 8. Segmented hard exudates

Finally, segmented hard exudates are validated with the ground truth as presented in Fig. 9. Segmented hard exudates by proposed method are illustrated in blue areas whilst yellow ones are ground truth areas that are labelled by experts. Segmented hard exudates are true if they are marked in the ground truth areas.

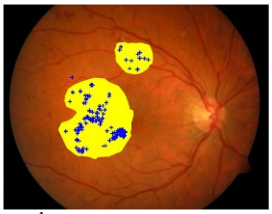


Fig. 9. Validated hard exudates.

Performance of the proposed method is evaluated by considering statistical measurement based on accuracy, sensitivity and specificity as defined in Eqs. (2) – (4). There are four parameters involved, i.e. true positive (TP), true negative (TN), false positive (FP) and false negative (FN).

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \tag{2}$$

$$Sensitivity = \frac{TP}{TP + FN} \tag{3}$$

$$Specificity = \frac{TN}{TN + FP} \tag{4}$$

The evaluation results of accuracy, sensitivity and specificity achieved are 99.99%, 90.38% and 99.99%, respectively. These results indicate that the proposed method successfully detected the hard exudates.

IV. Conclusion

A proposed method for detecting hard exudates was successfully developed by employing matched filter based method and morphological operation. The proposed approach was validated by using 60 fundus images taken from DIARETDB1 dataset. The average results of accuracy, sensitivity and specificity achieved were 99.99 %, 90.38 % and 99.99 %, respectively. This result indicated that the proposed method has a potential to be implemented as a part of DR grading system development to assist the ophthalmologist in analysing fundus images. Further study on other fundus image dataset can be conducted to evaluate the proposed approach.

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