IMAGE ENHANCEMENT TECHNIQUES FOR TELE-SLIT LAMP MICROSCOPY

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Received: May 20, 2010; Revised: Sept 20, 2010; Accepted: Sept 24, 2010

Abstract

Ophthalmologists need an Eye-Teleanalyzer that has a high-resolution image and no light reflection. A Slit lamp microscope, which is the main part of Eye-Teleanalyzer, can be improved by implementing the function of an auto focus system, eye-tracking system, and image enhancement method. The focus position is the position that gives the maximum focus value. However the reflection of light from the slit lamp can cause an error in finding the focus value algorithm. The reflection must first be identified and removed before calculating the focus values. The simulation result shows that the proposed algorithm can give the right focus position with trade off on computational time. Since the human eye is a spherical shape, slit lamp microscopy will focus only on a small part of the eye or only on the area of interest. To get an entirely sharp image, where all parts of the eye are in focus, a set of sharp eye images in different areas is needed to make the image mosaic method. This mosaic method can improve the resolution of the overall image. However, some sets of eye images are taken under different lighting conditions, which can lead to false mosaicking. The processing time is extremely long to process. To solve this problem, the gradient orientation pattern matching technique (GOPM) is used to eliminate the undistributed light intensity. The coarse-to-fine gray-scale matching strategy is introduced to reduce the computational time. The results show that the uses of GOPM help the mosaicking process, to give an accurate matching position which is very important for the image enhancement process. Also, the processing time is remarkably reduced.

Keywords: Image enhancement, image mosaic, slit lamp microscopy, Eye-Teleanalyzer

Introduction

An Eye-Teleanalyzer is used by ophthalmologists in central hospitals to diagnose the patients' eye diseases in rural areas. It will reduce significantly the cost and time of ophthalmologists' travel

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to remote areas and patients have no need to wait for diagnosis and can have continuing treatment (Tanta-ngai *et al*., 2008). From the reasons above, the Eye-Teleanalyzer needs to be improved and developed in order to have the sharpest and highest resolution image. However, problems arise when the area of interest of the eye has light reflection, returning a wrong focus position. Different light intensities over an eye image make a false matching position in the image enhancement process, which is used to produce a high resolution image.

An Eye-Teleanalyzer is composed of a slit lamp microscopy equipped with a camera and a motor, which is controlled by a control unit (Figure 1). The overall system in Figure 2 shows the patient and slit lamp microscope in a remote area, while the ophthalmologist is located in a central hospital using the internet to connect both areas (Gierl *et al*., 2007a, 2007b; Tanta-ngai *et al.,* 2008). To capture eye images, first a doctor at the central hospital controls the slit lamp microscope in the remote area in real time. Then, a position is selected; after that, the microscope captures the best focal image and sends it to the doctor's office via the internet.

When a doctor has the set of best focal images of the patient's eye in each position, image processing is used to find the focus position and produce the highest resolution image using the image mosaic method, which enhances the quality of images for diagnosis (Asmuth *et al*., 2001).

(a)

(b)

Figure 1. (a) Slit Lamp Microscope and (b) Control unit

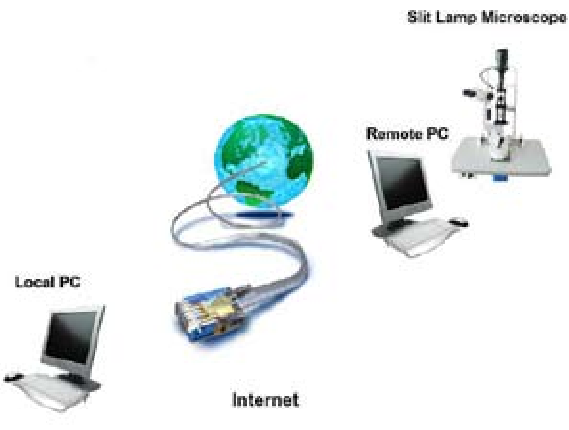


Figure 2. The overall system

Materials and Methods

Focus Value

A focus value is necessary for finding the focus position, and the operation of taking an image starts with the camera, equipped with the slit lamp, moving along the *z*-direction and capturing images along its movement as shown in Figure 3.

A set of eye images is obtained after this process. Each image is calculated for focus values by using the algorithm in Figure 4. This algorithm uses the set of images to perform the Sobel operation and then calculates the energy of the gradient image (Groen *et al*., 1985; Subbarao *et al*., 1993). The energy of gradient image can be found by finding the variance of intensities. There are some methods and algorithms which are used, like the Sobel operation (Jiewpaibul *et al*., 2008; Tanta-ngai *et al*., 2008), and vertical weighting mask (Groen *et al*., 1985; Gierl *et al*., 2007). However, the problem arises when the system is faced with the light's reflection from the slit lamp microscope. This reflection will cause an error in finding the focus value algorithm. The focus value will fluctuate and cannot be used. As a result, the objective in this part is trying to eliminate the light's reflection from the slit lamp microscope in order to increase the accuracy of the system.

Figure 5 shows the focus values of each image along the *z*–direction. It can be seen that the value is very high and the maximum focus value is at image number 39, which actually is a blur image as shown in Figure 6(a).

Figure 6 shows the region of interest, which is affected by light reflection. Figure 6(a) shows the blur image, which indicates from Figure 5 that it has the maximum focus value; this is supposed to be the sharpest image. Figure 6(b) shows the gradient image of Figure 6(a), which is used to calculate the focus value. It can be seen that the focusing point is on the reflection. This output, occurring

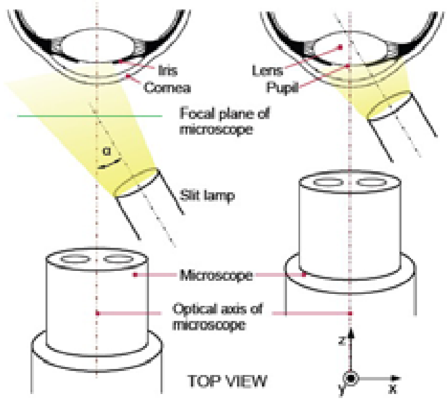


Figure 3. Movement of the slit lamp along the optical axis (z-axis)

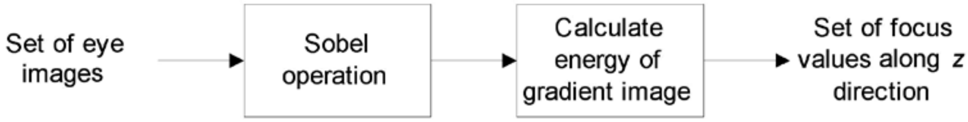


Figure 4. The previous algorithm used to calculate a set of focus values

from the reflection, can be dealt with by removing the reflection before performing the Sobel operation.

Deleting the Effect from Light Reflection

In order to remove the effect from the light reflection, the proposed method is applied with the process that is shown in Figure 7(a); first the reflection must be located by using the initial image to be the reference image, as shown in Figure 7(b).

The thresholding technique is applied (Figure 7(c)) to locate the reflection. The threshold value is fixed in this process, because the light reflection area has very large intensities, and can be easily separated from other details. After the thresholding process, the image dilation technique is applied to the thresholding image in order to cover all the reflections that occur in set of the eye images. Then, the dilation image must be inverted; the result is shown in Figure 7(d), and it can be seen that the black area is the area that needs to be removed. The mask will be multiplied with the eye images to eliminate the reflection. The overall process is shown in Figure 8; note that a binary mask for removing reflections is generated first then, the Sobel operator is applied to find the focus values. After that, the outputs from the Sobel operator are multiplied with the binary mask (Jaiwat *et al.*, 2009).

Figure 9 shows the focus value after deleting the reflection and shows the maximum focus value at image number 51 (Figure 10(a)), which is the sharpest image. It can be seen that, after removing the light reflection (Figure 10(c)), compared with before removing the reflection (Figure 10(b)), the result shows a clearer iris image.

Performance

Although the proposed method can eliminate the error from reflection, it uses more computational time in order to compute the focus value as shown in Table 1. The proposed method of finding focus value, by Sobel operation, uses 4.322 seconds, which is longer than the previous method.

Finding Focus Value by Weighting Vertical Mask

Due to the process of deleting the reflection, by Sobel operation, takes more time, with an increase of approximately 18% from the processing time, as shown in Table 1. The weighting vertical mask is used to compensate for the processing time. At first, this mask is developed to eliminate the effect of the eyelashes which are mostly in the vertical direction (Groen *et al.*, 1985; Gierl *et al.*, 2007). The 2 masks that are normally used in the Sobel operation are replaced by

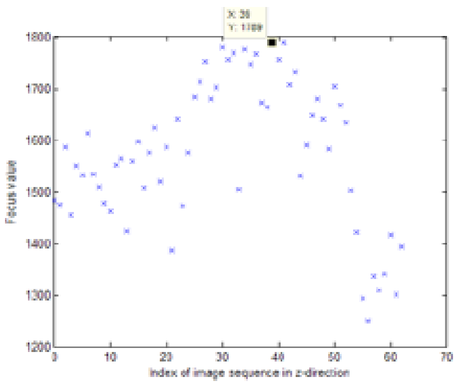
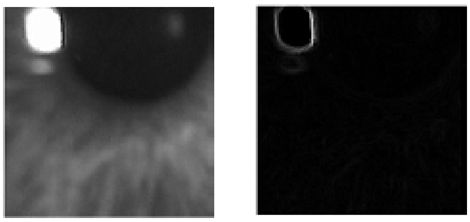
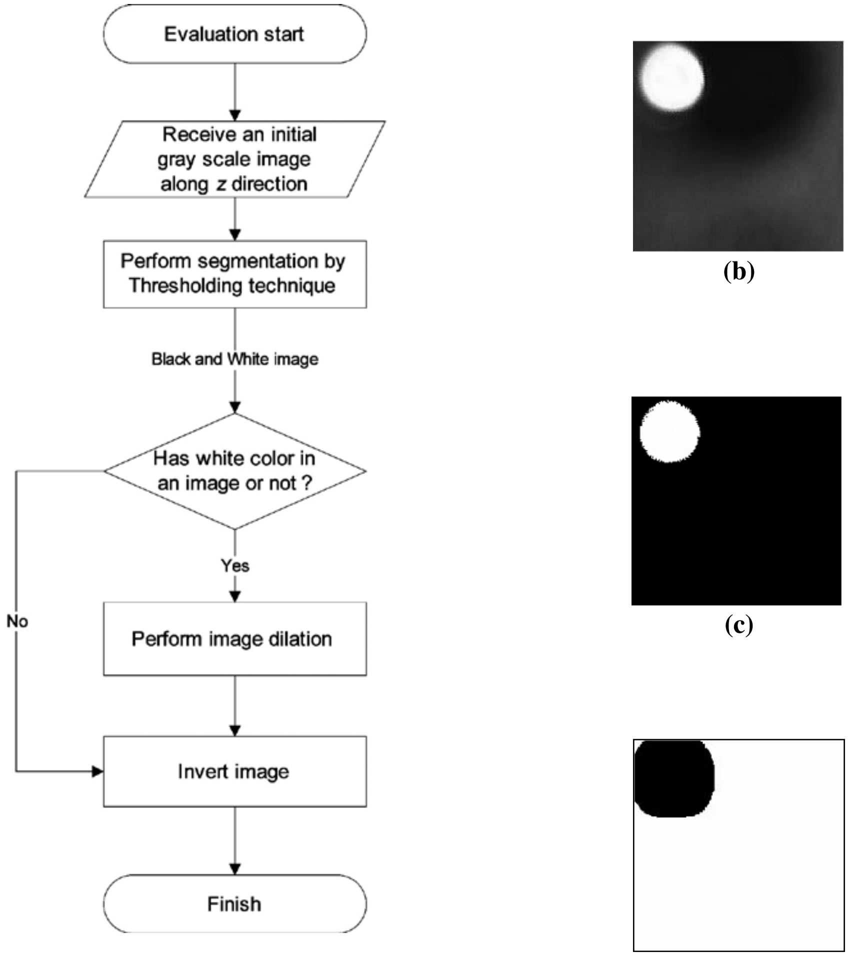


Figure 5. The focus value with effect of light reflection



(a) **(b)**

Figure 6. (a) The image with index 39 and (b) the edge of (a)



(a) **(d)**

Figure 7. (a) The proposed deletion of reflection algorithm
(b) The initial image in the sequence
(c) The threshold image
(d) The inverted image after dilating or mask for removing reflection

the following (1 × 11) vertical mask (Groen *et al*., 1985; Gierl *et al*., 2007).

$[-0.4, -0.4, -0.8, -1.2, -2, 0, 2, 1. 2, 0.8, 0.4, 0.4]^T$

Therefore, the block Sobel operation in overall process (Figure 8) is replaced by this 1-D vertical mask. The result shows that the weighting vertical mask can return a sharp image. Moreover, this mask is more robust to light reflection, compared with the Sobel mask. The following example shows the result using these 2 types of mask. Figure 11(a) (using another test set of eye images) shows the maximum focus value using the Sobel operation and shows that eye image number 30 is expected to be the sharpest image; however eye image number 30 is a blur image. The maximum focus value using the weighting vertical mask in Figure 11(b) returns the eye image number 58, which is a sharp image. This is the result from the structure of the mask, that the weighting vertical mask cannot detect the vertical edges (Gierl *et al*., 2007(a),

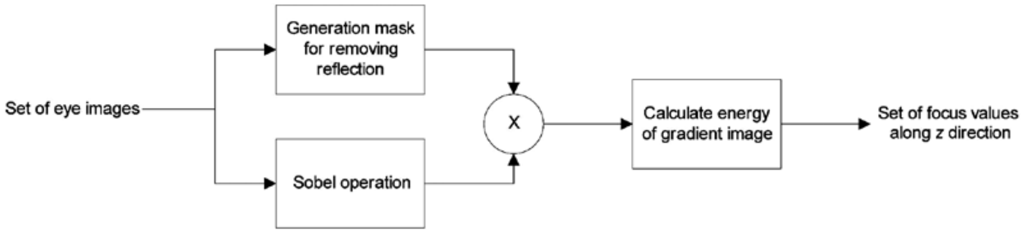


Figure 8. The overall process of proposed method

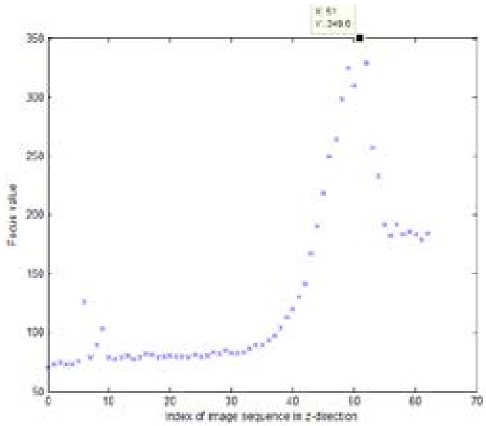


Figure 9. The focus value without reflection

(a) **(b)** **(c)**

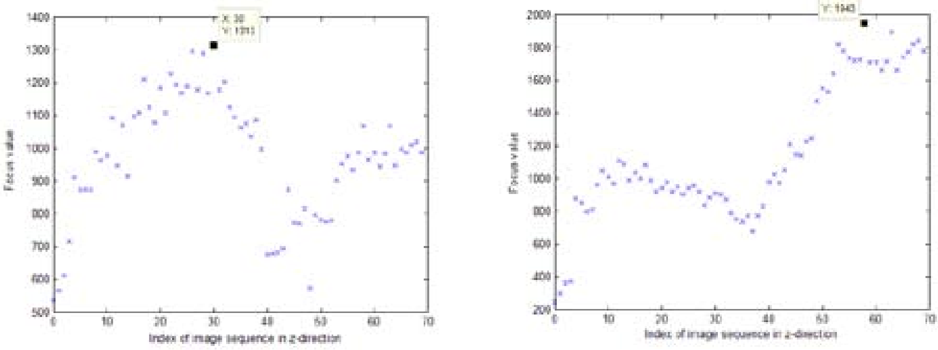
Figure 10. (a) The eye image number 51
(b) The edge before removing reflection
(c) The edge after removing reflection

Table 1. Average computational time of finding focus value process*

Method	Time (sec)
Previous Method	3.641
Proposed Method (delete light reflection by Sobel operation)	4.322
Proposed Method (delete light reflection by weighting vertical mask)	3.521

* Tested by PC computer Intel Core 2 Duo E6750 2.66 GHz RAM 2 GB bus 800 MHz.

2007(b)). For this reason, it will reduce the effect from the reflection as shown in Figure 12. Figure 13 shows the focus values plot after deleting the light reflection. The result, after deleting the light reflection from the Sobel operation (Figure 13(a)) and weighting vertical mask (Figure 13(b)), shows almost the same result, that the maximum focus value

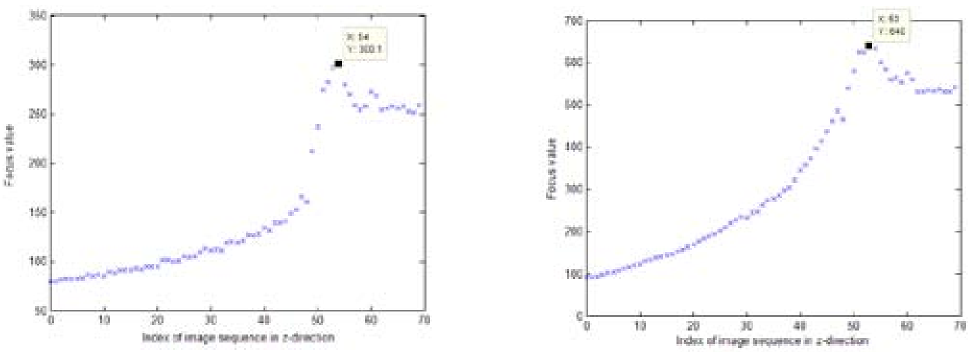


(a) (b)

Figure 11. (a) The result from using Sobel operation compared with (b) the focus value using weighting (1 × 11) mask

(a) (b)

Figure 12. (a) The gradient image using Sobel operation
(b) Gradient image using weighting vertical mask



(a) (b)

Figure 13. (a) Focus values by Sobel operation after deleting the reflection
(b) Focus values by weighting vertical mask after deleting the reflection

is from eye image number 53 and 54. Note that, the image numbers 53 and 54 are sharper than the image number 58 (the result in Figure 11(b)).

The Effect of an Eyelash

An eyelash is mostly composed of a vertical edge (Groen *et al*., 1985; Gierl *et al*., 2007). A weighting vertical mask can deal with this problem by neglecting these vertical edges. However, a problem arises when the area of interest has an eyelash that has a horizontal edge component and the use of the vertical mask will magnify the edge in the horizontal direction instead, so that the result is invalid. Figure 14(a) to (c) shows the effect from an eyelash.

Performance

Although the proposed method (Figure 8) can eliminate the error from light reflection, it uses more computational time in order to compute the focus value. The 1-D vertical mask, which uses only one vertical mask instead of two 2-D Sobel masks, has less computational time as shown in Table 1. The proposed method of finding focus value, by weighting vertical mask, uses 3.521 sec.

Image Enhancement

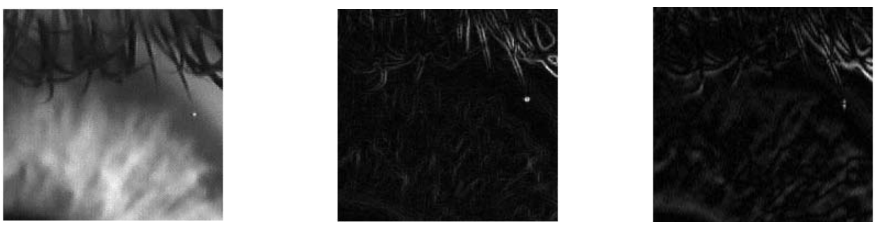
In the previous research (Jiewpaibul *et al*., 2008), the image enhancement process requires lengthy time to find the best matching position. Also false matching occurs in poor lighting conditions (Jaiwat et al., 2009; Kondo and Kongprawechnon, 2009a, 2009b). The problem of the lengthy computational time comes from the fact that the sum of absolute differences technique (SAD) which is performed for every pixel of the image. Another problem is that the SAD technique cannot give the correct matching position, because the SAD matching technique is dependent on image intensity (Jaiwat *et al*., 2009; Kondo and Kongprawechnon, 2009a, 2009b).

The gradient orientation pattern matching technique (GOPM) is used in this part to solve the different light intensities. The coarse-to-fine matching strategy is employed in this part for significantly reducing the computational time.

Image enhancement is achieved by the gradient orientation pattern matching technique (GOPM). A notable feature of the GOPM is that it is based on the unit gradient vectors (UGVs) of images, instead of image intensities [7][8]. The UGVs can be obtained by dividing the image gradient vectors by their magnitudes:

$$n_x = g_x / \sqrt{g_x^2 + g_y^2} \quad \text{and} \quad n_y = g_y / \sqrt{g_x^2 + g_y^2} \qquad (1)$$

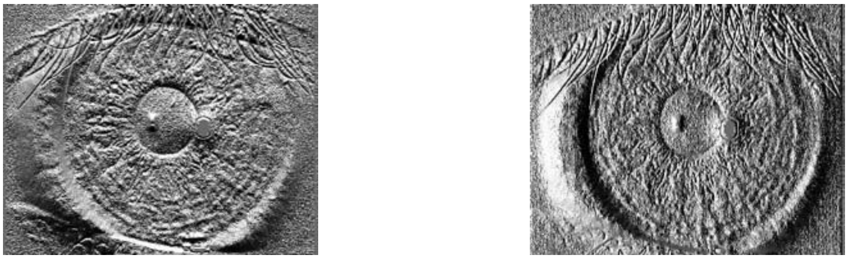
where g_x, g_y denote the image gradients in the x and y directions, and *nx, ny* the UGVs in the x and y directions. When the denominator is very small (low contrast regions), 0's are assigned to the unit vectors to avoid zero division.



(a) (b) (c)

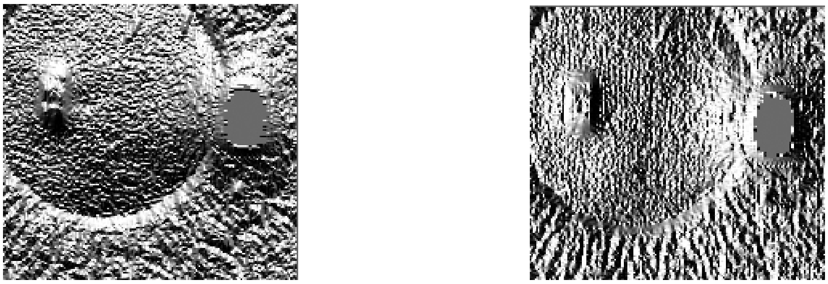
Figure 14. (a) Gray eyelash image
(b) Sobel operation
(c) Gradient image by weighting vertical mask

Because of the normalization step in Equation (1), the GOPM is independent of image intensities and works very well to match 2 images that have similar structural patterns but different intensities. Gradient orientation patterns comprise 2 images that are obtained as x and y components of the UGVs (Figures 15 and 16). The GOPM can be performed in the same way as conventional template matching methods with metrics such as the sum-of-absolute differences (SAD), the sum-of-squared differences (SSD), and cross-correlation (CC). To reduce the computation time, a coarse-to-fine template matching strategy is employed. Equation (2) shows the implementation of the GOPM using the SAD metric.



(a) **(b)**

Figure 15. A pair of gradient orientation patterns
(a) The x components (vertical components) of the UGVs of the eye image
(b) The y components (horizontal components) of the UGVs of the eye image



(a) **(b)**

Figure 16. A pair of gradient orientation patterns
(a) The x components (vertical components) of the UGVs of template No. 5
(b) The y components (horizontal components) of the UGVs of template No. 5

(a) **(b)**

Figure 17. (a) 9 spotlight images from 9 different images
(b) background image

$$\sum\sum\left(|I_{nx}-T_{nx}|+|I_{ny}-T_{ny}|\right) \quad (2)$$

where I_{nx} and I_{ny} are vertical and horizontal components of the UGVs of the background image, and T_{nx} and T_{ny} are vertical and horizontal components of the UGVs of a template image, i.e., the spotlight image.

For image enhancement, we firstly prepare a wide-view eye image, a so-called background image, that may not be entirely in focus (Figure 17(b)). Next, we obtain a set of spotlight images as shown in Figure 17(a) that are in focus and sharp. Using the focus value, we select nine on-focus subimages (spotlight images) from a set of images. Thus, the spotlight images may come from the different frames within the same set of images. The selected nine spotlight images cover the iris and pupil region of the eye. We then apply the GOPM to the background image and the set of spotlight images. Finally, each spotlight image is pasted on the background image at its best-matching position, producing a wide-view and also a wide sharp output image for ophthalmologists (image mosaicking). The entire flow of the image mosaicking is summarized in Figure 18.

In the proposed method, we employ a coarse-to-fine matching strategy for finding the best match position of each spotlight image. In the coarse matching stage, the template is scanned every 20 pixels vertically and horizontally. In the fine matching stage, the template is scanned every pixel around the best match point found in the preceding step. Finally, the spotlight image is to be patched on the background image.

Figure 19 shows the image enhancement results of the previous approach (Jiewpaibul *et al.*, 2008) and the proposed method. It clearly shows the superior performance of the GOPM over the traditional SAD template

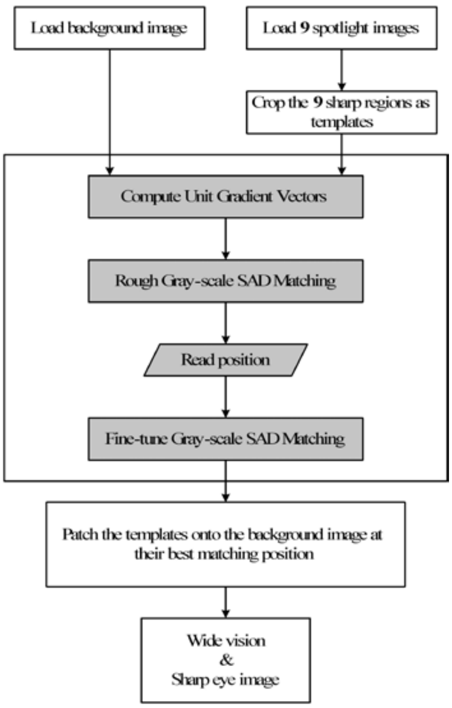
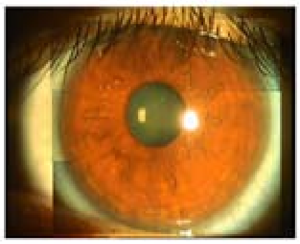


Figure 18. The flow chart of our image enhancement

(a)



(b)

Figure 19. (a) The image after mosaicking of previous method
(b) The image after mosaicking of proposed method

matching method. In addition, Table 2 shows the comparison between the computation times of the previous approach and the proposed method. The computation time has been significantly reduced by the coarse-to-fine matching strategy.

Conclusions

In this paper, an image processing technique for an Eye-Teleanalyzer is described. An improved methodology is proposed in order to improve the performance, speed, accuracy, and robustness of the system. These methods are: dealing with the auto focus value, removing the reflection, and image enhancement. For removing the reflection technique, the former algorithm of finding focus values has been changed by identifying the reflected area and creating a mask for removing that reflection. The result shows that the proposed method can calculate and indicate the right focusing image. However it uses more computational time.

A weighting vertical mask is used to deal with the computational time of the removing the reflection algorithm. This mask will replace the 2 Sobel masks normally used in finding the focus value. The result shows that using this mask will save computational cost and can give the right focus value; however, there is a tradeoff when the area of interest area has an eyelash. This mask tends to magnify the horizontal component of the eyelash.

For the image enhancement method, the unit gradient vector is used to deal with the set of eye images that have a different light intensity. Coarse and fine-tune gray scale GOPM matching techniques are introduced to solve the problem of the previous algorithm, which uses a tremendous amount of computational time. The result shows that the proposed algorithm gives fewer errors and uses much less computational time.

For further research, the programming should be done in C language by using the Open CV library, in order to implement a practical system and attain a shorter computation time.

Acknowledgement

The financial support from NECTEC's Young Scientist and Technologist Programme (YSTP: SP51-NT10) is gratefully acknowledged.

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Table 2. Average computation time and error of image enhancement process*

Method	Average computation time (sec)	Average error (pixel)
Previous method	637	70.2447
Proposed Method	25	2.2483

* Tested by MacBook Pro, Intel Core 2 Duo T9300 2.53 GHz, RAM 4 GB, Bus 1066 MHz.

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