

Enhancement of DNA Microarray Images using Mathematical Morphological Image Processing

Asral Bahari Jambek^{1*}, Khairul Anuar Mat Said^{1*} and Nasri Sulaiman^{2,3}

¹School of Microelectronic Engineering, Universiti Malaysia Perlis, Perlis, Malaysia

²Department of Electrical and Electronic Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia

³Institute of Advance Technology (ITMA), Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia

ABSTRACT

DNA microarray images contain spots that represent the gene expression of normal and cancer samples. As there are numerous spots on DNA microarray images, image processing can help in enhancing an image and assisting analysis. The mathematical morphology is proposed to enhance the microarray image and analyse noise removal on the image. This follows an experiment in which the erosion, dilation, opening, closing, white top-hat (WTH) and black top-hat (BTH) operations were applied on a DNA microarray image and its results analysed. Noise was completely removed by the erosion operation and the images were enhanced.

Keywords: DNA microarray image, mathematical morphology, image enhancement

INTRODUCTION

Microarray technology is widely known for allowing scientists to analyse the gene expression. Furthermore, microarrays make it easier to compare between normal and cancerous cells. For this study, deoxyribonucleic acid (DNA) microarray

containing microscopic DNA spots were deposited on the surface of a glass slide. Firstly, two samples of cDNAs (normal and cancerous cells) were labelled with different fluorescent dyes (Cy3 and Cy5) (Belean et al., 2015; Helmy & El-taweeel, 2013). Then, both samples were hybridized on the same glass slide. The glass slide was scanned using a green and red laser after the hybridization process was completed. A composite image was produced and the intensities of each spot were analysed. The sample that was labelled using Cy3 produced a green colour, while the sample labelled using Cy5 produced a red colour. If the two samples were in equal abundance, the yellow colour would have

ARTICLE INFO

Article history:

Received: 24 August 2016

Accepted: 02 December 2016

E-mail addresses:

asral@unimap.edu.my (Asral Bahari Jambek),
anuarsaid91@gmail.com;
keoinuar@gmail.com (Khairul Anuar Mat Said),
nasri_sulaiman@upm.edu.my (Nasri Sulaiman)
*Corresponding Author

appeared; if neither sample was present, it would have appeared as a black colour (Qin et al., 2005). Therefore, the gene expression of the DNA microarray images can be monitored. The DNA microarray images may contain noises and contaminations arising from the scanning process or other previous process stages (Qin et al., 2005; Wang et al., 2013). These problems can affect the whole microarray image process. Thus, image processing is proposed as a means to minimize or eliminate such problems.

Microarray image processing contains the following three stages: (1) gridding, which is a process of segmenting the microarray image into partitions, with each partition having only one spot; (2) segmentation, which is a process of differentiating between the foreground and background features; and (3) intensity extraction, which is a process of calculating the intensity that is available on the image (Harikiran et al., 2012; J et al., 2011). The noises on the microarray image are a major problem during the entirety of image processing. Some of them may generate wrong information about the gene expression. Besides, missing spots on the microarray image may also appear. Thus, the process of spot recognition is a difficult as the microarray image consists of noises that interrupt the image acquisition (J et al., 2013). It is more convenient if the noise is removed or minimized early. Image enhancement is an important method because it can recover several useful details of the image (Bai et al., 2012).

In this paper, mathematical morphological image processing was performed on a DNA microarray image and analysed. The operations were programmed using the MATLAB software; the output image for each operation is discussed. In the literature review several applications that have used mathematical morphology in image processing are presented, and followed by an explanation of the methodology adopted. The section on result and discussion all the experimental results are discussed, and followed by the conclusion.

LITERATURE REVIEW

Mehta et al. (2015) proposes the combination of pre-processing morphology and entropy calculation to enhance the ultrasound images of the gall bladder. The ultrasound images are first converted into greyscale and then into a black and white image using a threshold filter. The threshold value of this work is set at 0.18. By converting the image into a black and white able to distinguish between the foreground and background features. The erosion and dilation operations are used to improve the clarity of the image, in which the erosion shrinks the foreground features, while the dilation enlarges the foreground features. Results show the ultrasound image clearly shows the location of the gallstone and is better than the input image.

Mittal & Dubey (2013) proposes using morphological image processing for early detection of rheumatoid arthritis (RA). This disease is commonly caused by inflammation in the joints, fingers and knees. The erosion process shrinks the foreground features of the image, while the dilation process enlarges the foreground features of the image. Both processes use the same structuring element (SE) as a probe, while showing that morphological image processing provides a better understanding of the ultrasound image and monitoring of RA.

Yuan & Li (2015) demonstrates a switching morphological and median (SMM) filter for noise removal. Morphological operations, such as erosion, dilation, opening and closing, are applied in order to eliminate the noise. The noise pixel can be estimated by combining the output

of the conditional morphological filter with that of the improved median filter. This method produces higher peak signal-to-noise ratio (PSNR) values compared to boundary discriminative noise detection (BDND), fast switching median (FSM), convolution noise detection-based switching median (CNDSM), opening-closing sequence (OCS), efficient edge-preserving (EEP) and noise adaptive fuzzy switching median (NAFSM) filters. Based on the result, the proposed method removes the noise effectively and the details of the image are well preserved.

Rong-yu et al. (2012) are concerned with observing space objects using a full-frame transfer CCD camera to detect and locate stars and moving objects in space. During the observation, the CCD images that are produced contain a smearing effect because the camera shutter is often removed. The effect degrades the image quality and increases the difficulty of object recognition. The author proposes mathematical morphology in order to eliminate the smearing effect as well as improve the detection rates and position accuracies of stars and moving objects. The dilation operation filters the maximum value depending on the structural body. The erosion operation filters the minimum value depending on the structural body. The opening operations eliminate the bright details that reduce the size of a structural body. The closing operation eliminates the dark details that reduce the size of an SE. This paper uses TopHat and Spread TopHat methods to remove the long-strip signals in the CCD image. The structural body plays an important role in morphological results, such that different structural bodies give different results. Results show mathematical morphology improves the detection rate and position accuracies of stars and moving objects by eliminating the smearing effect.

Zhang et al. (2011) proposes using an improved morphological edge detection method for an edge detection operator and an iterative thresholding method for a better thresholding value in order to identify foreign fibres in cotton products. Dilation and erosion algorithms are used in the edge detection operator. Each colour (R, G and B) is then taken into account in the image, while the improved morphological edge detection consists of the edge detection for each colour, which is called the edge intensity value; if the value of it is greater than the given threshold, it is considered as edge pixels from the image. Therefore, the iterative method is a method to select the threshold value automatically because different situations lead to different light intensities. Based on the result, the proposed methods provide a better accuracy for the segmentation of foreign fibres and improve the processing time compared to conventional methods.

Mathematical morphological image processing operations helps to enhance the features on the image. Different applications will use different operations of mathematical morphology. Table 1 shows the comparison between different applications that apply mathematical morphological operation, which will be discussed later. Yuan & Li (2015) uses the SMM filter to determine the noise pixels in relation to the removal process. TopHat and Spread TopHat transforms in method (Rong-yu et al., 2012) are discussed, in which the smearing effect may be eliminated by choosing suitable SEs. Zhang et al. (2011) uses a combination of morphological edge detection and iterative thresholding to improve the segmentation process in order to identify foreign fibres in cotton. From the five applications, it can be seen that mathematical morphological operations may enhance the image and preserve image information well. In the next section, the experiment undertaken in this work is presented.

Table 1
Comparison of different applications

Method	(Mehta et al., 2015)	(Mittal & Dubey, 2013)	(Yuan & Li, 2015)	(Rong-yu et al., 2012)	(Zhang et al., 2011)
Application	Medical	Medical	Case study	Astronomy	Agriculture
Type of image	Colour	Greyscale	Greyscale	Greyscale	Colour
Threshold	Yes	No	No	No	Yes
Accuracy	N/A	N/A	N/A	N/A	N/A
Complexity	Low	Low	Normal	Normal	Normal
Special feature	N/A	N/A	SMM	TopHat and Spread TopHat	Morphological edge detection and iterative thresholding

METHODOLOGY

This section discusses mathematical morphological image processing of microarray image (Microarrays Inc., 2016). The mathematical morphological process is programmed using the MATLAB software. Figure 1(a) shows a part image with a size of 441×431 pixels, compared with the real microarray image of 2200×7300 pixels, which is used as the input image for this work. Figure 1 (b) shows the SE that is used as a probe for mathematical morphology. An SE of a disk shape, with a radius of four pixels, is chosen as the input image to be used, containing DNA spots, which are generally in circle shape. Therefore, the disk shape in structuring is used to produce similarity with the information interest on the input image. The spots on the input image provide the important information, so that the SE of mathematical morphology may enhance the spots area that forms the background. The size of the SE depends on the spot size. In this work, the radius of four pixels is chosen because the average size (diameter) of the spots on the input image is 8~9 pixels.

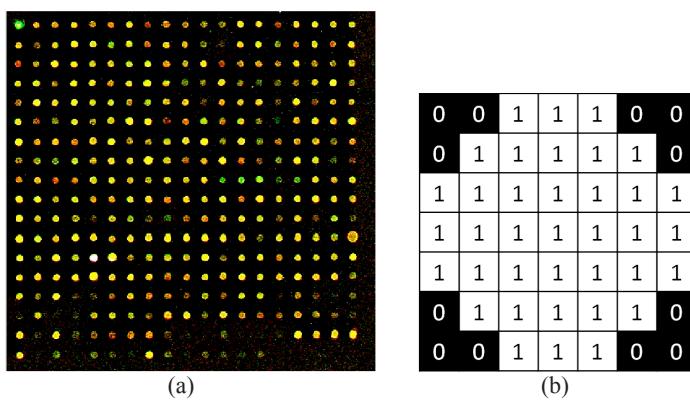


Figure 1. (a) Input image of a 441×431 pixels region from a real microarray image of 2200×7300 pixels;
(b) the SE of a disk shape with a radius of four pixels

Mathematical Morphological Image Processing

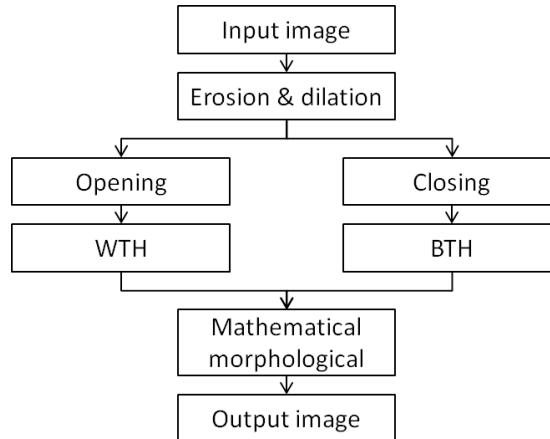


Figure 2. The flowchart of mathematical morphological image processing

Figure 2 shows the flowchart of mathematical morphological image processing where the basic process is erosion and dilation. Erosion is a process of removing the foreground features of an image, while dilation is a process of adding the foreground features on the image. Both the erosion and dilation processes depend on the SE. Opening is a process to remove the foreground objects that are smaller than the SE. Closing is a process of removing the background objects that are smaller than the SE. Both opening and closing control the uses of erosion and dilation to enhance the foreground and background features. During the opening, the input image (IM) will undergo erosion first, followed by dilation. Meanwhile, in closing, the IM will undergo dilation first, followed by erosion. The major process of mathematical morphology involves the white top-hat (WTH) and the black top-hat (BTH). The WTH enhances the foreground features on the image in line with the different results obtained between the IM and the opening operation. BTH enhances the background features of an image giving results that differ from the closing operation and the IM. Mathematical morphology is the result of the IM added to the WTH, then subtracted from the BTH. The opening, closing, WTH, BTH and overall operations are defined as follows (Li et al. 2015):

$$\text{Opening} = \text{IM} \ominus \text{SE} \oplus \text{SE} \quad (1)$$

$$\text{Closing} = \text{IM} \oplus \text{SE} \ominus \text{SE} \quad (2)$$

$$\text{WTH} = \text{IM} - \text{Opening} \quad (3)$$

$$\text{BTH} = \text{Closing} - \text{IM} \quad (4)$$

$$\text{Mathematical morphological} = IM + WTH - BTH \quad (5)$$

where \ominus and \oplus respectively denote the erosion process and the dilation process.

RESULTS AND DISCUSSION

In the previous section, the mathematical morphological algorithm was presented. The algorithm was run on the input image as shown in Figure 1(a) using the SE shown in Figure 1 (b). In this section, the experimental result for each process in the mathematical morphological operation will be presented. All the workings are performed using the MATLAB software running on the Windows operating system. Firstly, the input image will convert into the greyscale image, as shown in Figure 3 (a). The image result for each operation is zoomed in with 161×166 pixels, which contain 7×7 spots for ease of analysing and understanding each operation, as shown in Figure 3 (b).

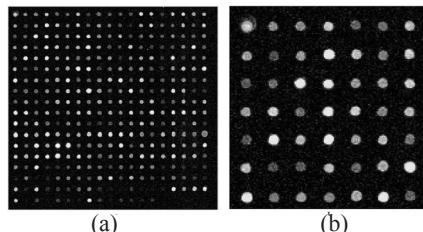


Figure 3. (a) The greyscale image of the input image; (b) the rescale input image consists of 7×7 spots

Opening, Closing, Erosion and Dilation Operations

The erosion operation shrinks the foreground features depending on the SE, as shown in Figure 4 (a). Based on the result, the spots (foreground features) on the image shrink due to the erosion operation. The shrinking causes a decrease in the foreground area compared to the input image. At this point, the noises that are smaller than the SE are completely removed. Besides, the spots that are smaller than the SE can also be removed, so selecting the appropriate size of the SE is important for this operation. The dilation operation enlarges the foreground features depending on the SE, as shown in Figure 4 (b). Based on the result, the spots (foreground features) on the image become larger due to the dilation operation. The enlargement causes a decrease in the background area compared to the input image. At this point, the noises are also enlarged with the spots which might combine with other foreground features if the size of the SE is too large.

In the opening and closing operations, opening is a process to remove the foreground objects that are smaller than the SE while closing is a process of removing the background objects that are smaller than the SE. From the result in Figure 4 (c), it shows that the opening operation removes the foreground object that is smaller than the SE compared to the input image. Based on the result, the opening operation is generally run as the dilation operation on the image result from the erosion operation in Figure 4 (a). From the erosion operation, the foreground object that is smaller than the SE is already removed. Thus, the opening operation is

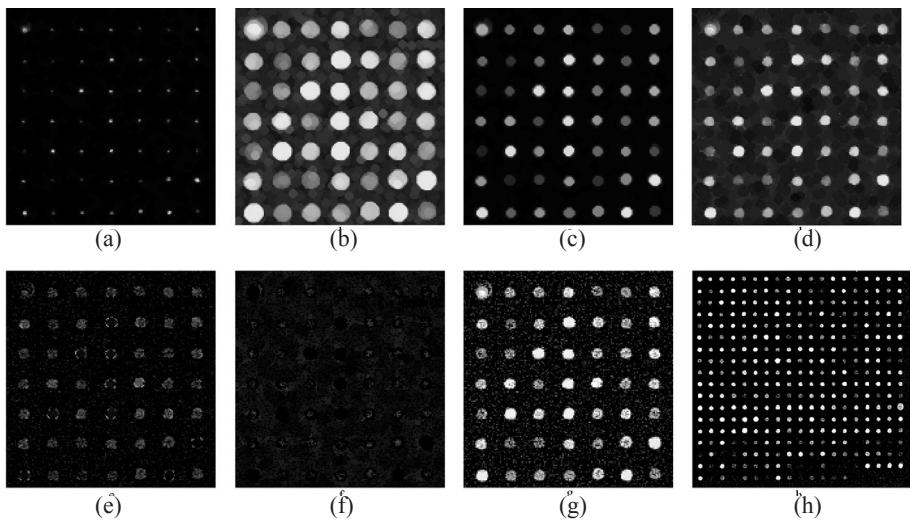


Figure 4. (a) The result of the erosion operation; (b) the result of the dilation operation; (c) the result of the opening operation; (d) the result of the closing operation; (e) the result of the WTH operation; (f) the result of the BTH operation; (g) the result of the mathematical morphological operation; (h) the final result of the full scale of the input image

the result of the enlargement of the foreground object that remains after the erosion operation. The opening operation follows the mathematical theoretical state, as given at (1).

The result in Figure 4 (d), shows that the closing operation removes the background object that is smaller than the SE compared to the input image. Based on the result, the closing operation is generally run alongside the erosion operation on the image resulting from the dilation operation in Figure 4 (b). From the dilation operation, the foreground features are enlarged, with some of them combining with other spots or noises. Thus, the closing operation is the result of shrinking the foreground object on the image resulting from the dilation operation. The closing operation follows the mathematical theoretical state given at (2).

Mathematical Morphological, WTH and BTH Operations

Next, the major operations in mathematical morphology take place, which concern the WTH and the BTH. The WTH is the difference between the input image and the opening operation result, as stated in (3). Based on the result in Figure 4 (e), the pixel in the remaining in the foreground is better than the image of the opening operation. The BTH is the difference between the closing operation result and the input image, as stated in (4). Based on the result in Figure 4 (f), the foreground features that remain are the exceeded pixels in the foreground on the image result from the closing operation compared to the input image. Finally, from the result of the WTH and the BTH, the enhancement of the image can be produced. The mathematical morphological operation is a process where the input image is added to the image produced from the WTH operation which is then subtracted with the image result from the BTH operation, as stated in (5). Based on the result in Figure 4 (g), the image becomes sharper and clearer compared to the input image. Figure 4 (h) shows the final result of mathematical morphology on the full-scale input image (Figure 3 (a)).

CONCLUSION

This paper shows the mathematical morphological image processing has better enhancement of the microarray image. The erosion and dilation are the fundamental operations to the mathematical morphology, while the opening and closing operations to enhance the foreground and background features, respectively. Lastly, the mathematical morphological operation produces the enhancement image by adding the input image and the WTH image, and then subtracting the BTH image. The results show the mathematical morphological image processing compared to the input image. Besides, during the erosion operation, the noises are completely removed.

ACKNOWLEDGEMENT

This research was supported by the Science Fund 2015 from the Ministry of Science, Technology and Innovation (MOSTI), Malaysia.

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