International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 2, February - 2014

Enhancement of Latent Fingerprints using Morphological Filters

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***Abstract*—With science being capable of quantifying many geometrical aspects of a structure which more or less goes hand in hand with human intuition and perception, Morphological Image Processing gets its inception as a most important tool in the field of Digital Image Processing which emphasizes on studying geometric structure of an image. The field of mathematical morphology contributes a wide range of operators to Digital Image Processing with all of them based on a few simple mathematical set theory concepts. Some common usages include detection of edges in a binary image, removal of noise from that image, enhancement of the image which also includes segmentation. The structural relationship between each part of an image could be well found and comprehended while processing with morphological theory. Morphological techniques typically probe an image with a small shape or template known as a structuring element which is positioned at all possible locations in the image and is compared to the pixels in the corresponding neighborhood. The way these comparisons are carried out is the difference in Morphological Operations. A noisy and cluttered image can be processed morphologically and editing can be done based on the size and shape of the objects of interest so that the noise and clutter will be removed. Morphological Image Processing, where the information of the image is not lost, can be substituted for a Linear Image Processing as it sometimes distorts the underlying geometric form of an image Morphological Image Processing is used to reconstruct the original image through Dilation, Erosion, Opening and Closing techniques for a finite no of times. This technique can we well adapted to a wider range of problems which includes Tumor detection and measurement of size and shape of internal organs in the field of Medical Image Analysis, etc. and Recognition and interpretation of objects in a scene, control of movements (motion control) and visual feedback that provides execution in the rapidly evolving field of Robotics. This paper throws light on one of the most important practical aspect of Morphological Image Processing and it successfully performs the Fundamental and Compound operations of Morphological Image processing on Binary images in FORENSIC Fingerprint Enhancement and reduction of noise in finger print images.**

Keywords: Closing; Dilation; Erosion; Latent fingerprint; Opening

I. INTRODUCTION

The general basis of Morphological Image Processing is to use the Structuring Element, a predetermined geometric shape to analyze two valued images. The branch of biology that deals with the form and structure of flora and fauna (plants and animals) is known as Morphology.

In order to extract significant features from images that are useful in representation and description of region shapes, a well suited approach is the Morphological (Shape-Based) processing which refers to specific operations where an object is HIT or FIT with structuring elements. Thus, the two valued images are reduced to a more revealing shape. The structuring elements are shape primitives that are developed to represent some aspect of the information or noise. One can perform different mathematical transformations on the data by applying the structuring elements in various algebraic combinations. Generally, Morphological Image Processing technique is applied for binary images and grey scale images in various fields.

A. Digital Image Processing

Digital Image Processing is evolving day by day which involves the manipulation and interpretation of Binary Images that are digitalized with the aid of a computer and is an extremely broad subject which often involves mathematically complex procedures. On the other hand, the central idea behind Digital Image Processing is quite simple. The binary image is fed into the computer and it is digitalized to one pixel at a time which is in turn programmed to insert the digitalized data into an equation or a process (a series of equations) and then stores the output. The output can be further processed or displayed directly. This field is particularly employed to solve a variety of problems which are often unrelated; however they commonly require methods that are capable of enhancing pictorial information for human interpretation and analysis.

B. Fingerprint

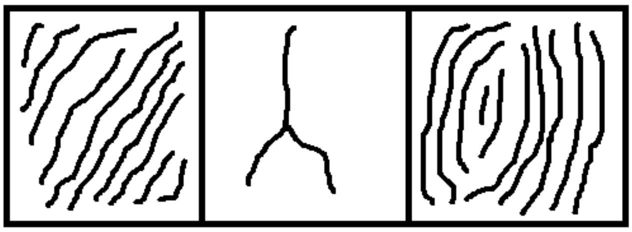
The fingerprint is a unique pattern possessed by a finger; which usually involves impression of the edges and furrows present on all parts of a finger which throws light on the similarities present in local windows, analogous to parallelism and the average width [1]. However, Intensive research on Fingerprint recognition shows that fingerprints are not distinguished by their ridges or furrows but by Minutia, the features that are some abnormal points present on the ridges [2].

There are two most significant Minutia types that are reported:

a) *Ridge Ending*: It is the abrupt ending of a ridge with no further continuations.

b) *Ridge Bifurcation*: It is a single ridge that divides two ridges.

Fig. 1. Fingerprint image from a sensor



2. a) Ending   2. b) Bifurcation   2.c) Short Ridge

Fig. 2. Types of Minutia

Fingerprints have always been employed as evidences of crime since 19th century; which proves to be one of the most important tools employed in Forensics. In cases where the offenders could not be determined or when no witnesses were found, Latent Fingerprints are useful. Those are nothing but impressions that are left on the surface and caused by the ridges on the skin which in most cases are either degraded or incomplete. The locations of Minutiae on a finger print pattern help us to distinguish one fingerprint from another or in other words, Minutiae provide the uniqueness required for distinction of fingerprints [3]. Morphological Image Processing is primarily used to enhance the degraded, incomplete or noisy Latent Fingerprints [4, 5]. Enhancement of Images and its Restoration are used to process degraded or noisy images of unrecoverable objects or results of experiments that are too expensive to duplicate. In fields that are related to physics, few newly emerged computer techniques are routinely enhancing the images of experiments in areas like electron microscopy and high-energy plasma.

II. IMAGE DATA

An image is usually transformed into Two-Dimensional light intensity function. On the basis of 2-D array of numbers, the images are usually classified into three different forms:

- Binary Image
- Grey Tone Image
- Color Image

A. *Binary Image*

The Image data of a Binary Image is either Black (representing ‘0’) or White (representing ‘1’). Often, if grey levels of a digital image range from 0 to 1, we call them Binary Images in which the White Pixels normally represent Foreground Regions and black pixels denote the Background Region. e.g.: A binary image can be digitalized in the following way:

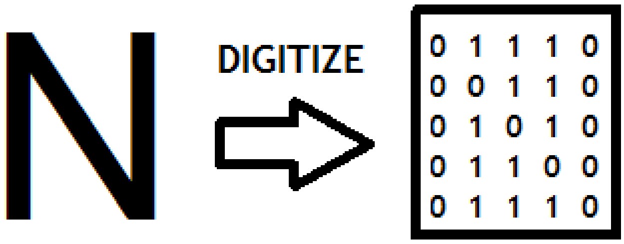


Fig. 3. Representation of a binary image

B. *Grey Scale Image*

The intensity value of a grayscale image is usually used to represent height above a base plane which in turn represents a surface in 3-Dimensional Euclidean Space [6].

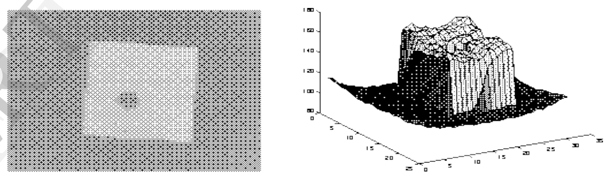


Fig. 4. Euclidean Space representation

III. MATERIALS AND METHODS

A kernel is a reserved term for similar objects used in convolutions. The structuring elements, 2-Dimensional, consisting of a matrix of 0’s and 1’s is used to probe the input image. The center pixel of the structuring element is called the origin that identifies the pixel of interest: the pixel being processed. The neighborhood of the structuring element is represented by the pixels of the structuring element that contain 1’s.

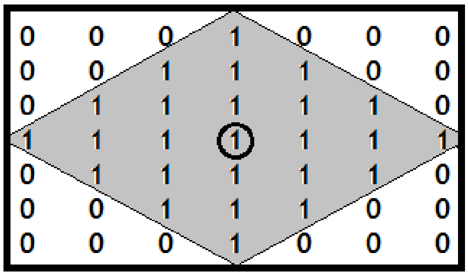


Fig. 5. Structuring element

A. *Structuring Element*

If we superpose a structuring element in a binary image, each pixels of the binary image is associated with the corresponding pixel of the neighborhood under the structuring element. This operation is rather logical than arithmetic in nature. **Ex**.: Suppose we are provided with two 3 * 3 structuring elements

$$S1 = \begin{bmatrix} 1 & 1 & 1 \\ 0 & 1 & 0 \\ 1 & 1 & 1 \end{bmatrix} \quad S2 = \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

Fig. 6. (3*3) Structuring Elements

In a given image A, B, C are three positions where the S1 and S2 Structuring Elements should be positioned.

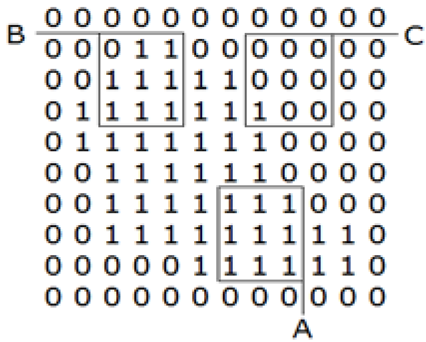


Fig. 7. Fitting and Hitting of Structuring Elements S1 and S2

B. *Fit*

If all pixels of the structuring element are set to '1', it is said to FIT the image which then corresponds image pixel to be set to '1'. When testing for a fit, if the structuring element is ignored, all the pixels are set to '0'. In the above example, both S1 and S2 fit the image at 'A', S2 fits the image at 'B' and neither S1 nor S2 fits at 'C'.

C. *Hit*

The digitalized binary image can be HIT by the structuring element if all its pixels is set to '1' and the corresponding image pixel is also set to 1. If the corresponding structuring element pixel is '0', we ignore image pixels. If we consider the above example, both the structuring elements S1 and S2 will HIT the image in neighborhood 'A' which will hold true at 'B' also. If we consider the neighborhood 'C', only the structuring element S1 will HIT the image. With reference to the above concept, HITS will correspond to Union and FITS will correspond to Intersection. Moreover, we can also replace the set operations Intersection and Union by the Boolean operators 'AND' and 'OR'.

IV. MORPHOLOGICAL FILTERS

A number of Morphological Filters can be employed for enhancement of images. In this paper, four such filters that are most predominantly used are being used. They play a major role in Noise Suppression and Enhancing images [7 - 10].

A. *Dilation*

Dilation is one of the important Morphological operations which can be performed both on Binary and Grey Tone Images. It is mainly used to extract the outer boundaries of the given images which cause objects to dilate or grow in size. The nature and the quantity that the images get dilated depend on the choice of the structuring element. Dilation usually makes an object larger by adding pixels around its edges. Symbolically, we represent Dilation by,

$$\text{Dilation} = A \oplus B \qquad (1)$$

Where, 'A' represents the image and 'B', the structuring element of size (3*3)

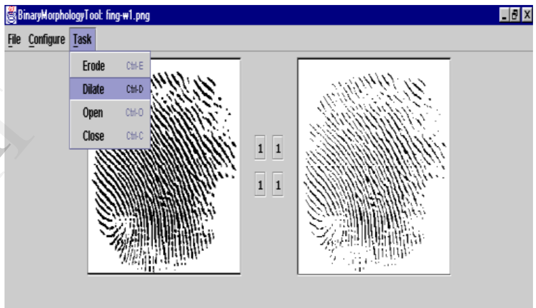


Fig. 8. Dilation operation on Latent Fingerprint

If the amount of Dilation has to be computed, we ought to position the structuring element such that its origin is at pixel co-ordinates (x,y) and the following rule is applied:

$$G(x,y) = \begin{cases} \text{'1' - if B hits A} \\ \text{'0' - otherwise} \end{cases} \qquad (2)$$

After having applied the same formula for all pixel co-ordinates, Dilation creates new image which shows all the location of a structuring element origin at which the structuring element HITS the input image. It will add a layer of pixels to both the inner and outer boundaries of regions to an object which enlarges it eventually, shrink the holes enclosed by a single region and will also make the gaps between different regions smaller. Dilation usually tends to fill any small intrusions into a region's boundaries whose results are influenced not alone by the size but also by the shape of the structuring element. The dilation operation for a binary image is as follows,

$$D(A, B) = A \oplus B \qquad (3)$$

Where, 'A' represents the image and 'B', the structuring element of size (3*3)

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 2, February - 2014

B. Erosion

Erosion can be performed on both Binary and Grey images which generally helps in extracting the inner boundaries of the given image. It causes objects to shrink by removing or eroding away the pixels on its edges.

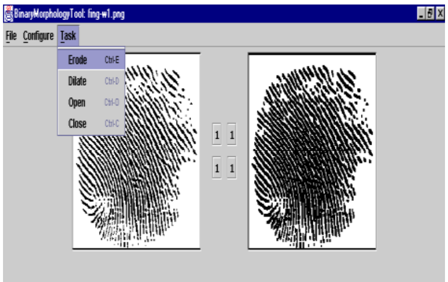


Fig. 9. Erosion operation on Latent Fingerprint

The amount of shrinkage depends upon the choice of the structuring element. Symbolically, the Erosion of an image ‘A’ by a structuring element ‘B’ is denoted as,

$$\text{Erosion} = A \ominus B \quad (4)$$

To compute the Erosion, we position ‘B’ such that its origin is at image pixel co-ordinate (x, y) and apply the rule.

$$G(x, y) = \begin{cases} \text{‘1’ if ‘B’ Fits ‘A’}, \\ \text{‘0’ – otherwise} \end{cases} \quad (5)$$

In order to remove a layer of pixels from an object, Erosion operation can be employed. The erosion operation performed on the image makes sure that the pixels in both inner and outer boundaries are eroded thereby enlarging the holes present in the image. This operation helps to remove all possible extrusions on the boundaries of the image. Generally, the size of the structuring element determines the result of erosion operation. It is used to provide a pronounced effect when a large structuring element is employed. The same can be obtained by using a small structuring element on a condition that it has to be carried out iteratively. For an image ‘A’ and structuring element ‘B’, Erosion operation can be represented symbolically as,

$$E(A, B) = A \ominus B \quad (6)$$

Where, ‘A’ represents the image and ‘B’, the structuring element of size (3*3)

C. Opening

Fig. 10. Opening operation on Latent Fingerprint

Opening is a very powerful operator which includes the operations of both Erosion and Dilation. It merely stands for “Separation of Objects”. The Expansion of the image provided by the Dilation Operator and the Shrinking of the image provided by the Erosion operator helps Opening to smooth the image and also facilitates breaking of Isthmuses that are generally narrow and elimination of protrusions that are generally thin. For a structuring element ‘B’ and the image ‘A’, the opening operation can be represented as **A** ○ **B** and is expressed symbolically as,

$$A \circ B = (A \ominus B) \oplus B \quad (7)$$

In the opening operation, the image is first eroded and then dilation is being carried out on the eroded image. This is used to smoothen the contour the image. This process can involve a number of erosion operations before the image becomes fully eroded and then dilation is being carried out.

D. Closing

Closing is yet another powerful operator which is quite similar to Opening operator. It has inclusions of both Erosion and Dilation operators. It literally stands out for “joining the objects”. The contour of the region can be smoothened by the utilization of the closing operator

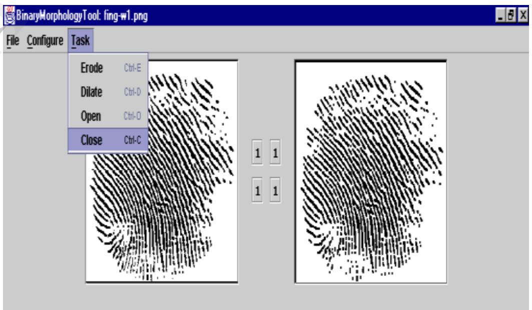


Fig. 11. Closing operation on Latent Fingerprint

However, contradicting Opening operation, Closing operator combines narrow breaks and long Gulf present in the images thereby eliminating holes in the contour. For an image ‘A’ and structuring element ‘B’, Closing can be mathematically represented as,

$$A \bullet B = (A \oplus B) \ominus B \quad (8)$$

Closing operation involves dilation of the given image as the first step. After dilating the image, erosion is being performed on the images. Several dilation operations can be performed and after dilating the image, the erosion operation is being carried out.

V. JAVA IMPLEMENTATION

The MIP operations can very well be implemented using MATLAB. However, we have rested to java implementation of the above mentioned Morphological Image Processing (MIP) technique [11, 12]. Unlike MATLAB, the images aren’t subjected to normalization and exact operations are performed without approximation thus providing more reasonably output with more accuracy.

A. *Dilation Filter*

```
for (int y = 0; y < (ht); y++)
{for (int x = 0; x < (wd); x++)
{index = x + y * wd;
pel [index] = (byte) (255 – pel [index]); } }
```

B. *Erosion Filter*

```
for (j=0; j< n Iterations; j++)
{ for (int y = 1; y < (ht - 1); y++)
{ for (int x = 1; x < (wd - 1); x++)
{ index = x + y * wd;
If (pel [index] == 0)
{ p1 = (pel [index – wd - 1] & 0xff);
p2 = (pel [index - wd] & 0xff);
p3 = (pel [index - wd + 1] & 0xff);
p4 = (pel [index - 1] & 0xff);
p5 = (pel [index] & 0xff);
p6 = (pel [index + 1] &0xff);
p7 = (pel [index + wd - 1] &0xff);
p8 = (pel [index + wd] &0xff);
p9 = (pel [index + wd + 1] &0xff);
addpel =  p1 + p2 + p3 + p4 + p6 + p7 + p8+  p9;
if (addpel >= pelThreshold)
{  remain [index] = (byte) 255;}
else {  remain [index] = 0;}
else {  remain [index] = (byte) 255;}}
```

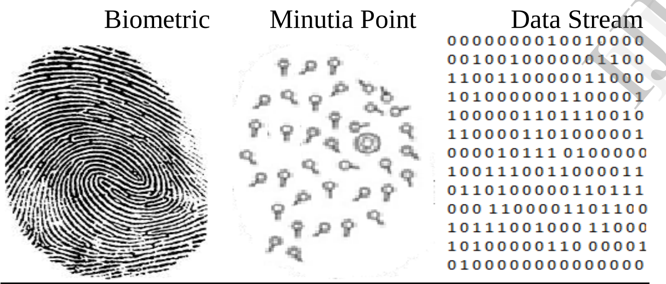


Fig. 12. Minutia Point Extraction and Data Stream Generation

The java platform is used to provide a more convenient representation for binary images that make the image processing software implementation to be relatively easy and straight forward. The JAVA implementation facilitates a Graphic User Interface to perform the operations of the above mentioned Morphological Filters.

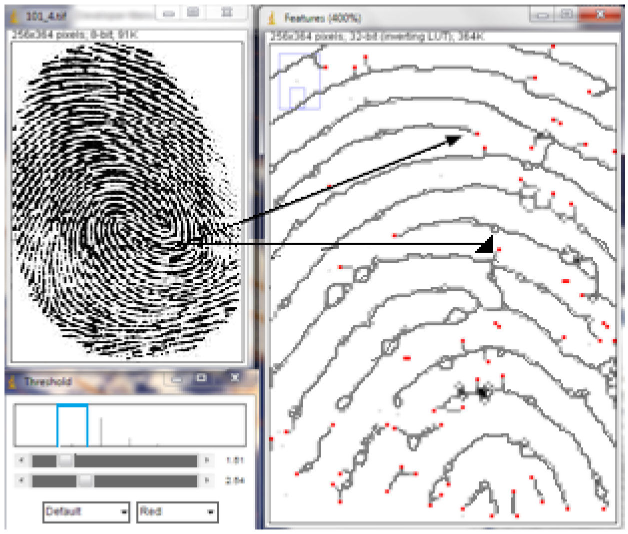


Fig. 13. GUI for Morphological Filters

VI. CONCLUSION AND FUTURE SCOPE

Morphological Image Processing (MIP) operations can be performed on a diversified spectrum of applications which constitute:

a) **Medical image analysis:** MIP finds applications in medical field through detection of Tumor cells, measurement of internal organs in terms of their size and shape, etc.
b) **Robotics:** MIP operations can be employed in Artificial Intelligence through its provisions for recognizing and interpreting objects in a video sequence, controlling the object's motion parameters, etc.
c) **Radar imaging:** MIP also finds applications in Radio Detection and Ranging where it is employed for detection and identification of objects

It can also be extended to Color image concepts and 24-bit True Color concepts. The special feature of Automatic selection of Structuring element for object classification through Morphology is still challenging to this technique and has been chosen to be the major direction of the future work.

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