A Method for Filling Holes in Objects of Medical Images Using Region Labeling and Run Length Encoding Schemes

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ABSTRACT—This paper presents a new method for filling holes in objects of binary images. Further it analyses the performance of other existing holes filling operations in binary form of medical images. Hole filling operations are widely used in medical image processing today. Almost all the medical image processing operations produce a binary form of original image at any stage. The binary images are normally produced by simple segmentation techniques such as thresholding. They contain foreground objects surrounded by background regions. Sometimes a set of background regions lying completely within the foreground regions due to imperfection in the binary conversion identified by the optimal thresholding. It is known as holes within the foreground objects or Region of Interest (ROI).

First we should know what is a hole in an image. The mathematical definition of hole is given by Sonka et al. [1]. Assume that $R_i$ are disjoint regions in the image which were created by the relation to be contiguous, and further assume that these regions do not touch the image limits (meaning the rows or columns in the image matrix with minimum and maximum indices). Let region $R$ be the union of all regions $R_i$; it then becomes sensible to define a set $R_c$ which is the set complement of region $R$ with respect to the image. The subset of $R_c$ which is contiguous with the image limit is called background, and the rest of the complement $R_c$ is called holes. Hence a hole is an area of dark pixels surrounded by light pixels in gray images and black pixels surrounded by white pixels in binary image.

Variety of hole filling methods are developed and used by researchers for medical image analysis study [1]–[6]. They are Areafill operations [2], Morphological operations [1], [4], Floodfill operations [6]. Sometimes a combination of these methods along with image subtraction is used to identify the holes effectively [2].

In this paper we propose an algorithm for filling holes that appear within the binary brain mask. The proposed approach is based on Run Length Encoded Data (RLED) of binary image and region labeling procedure. The proposed operation is fully automatic and no user intervention is required at any stage. This automatic process is best suitable holes filling module in any brain image analysis pipeline.

KEYWORDS: Run Length Encoded Data, Region Labeling, Foreground, Background, Holes.

I. INTRODUCTION

Hole filling operations are widely used in medical image processing today. Almost all the image processing operations of medical scans produce a binary form of original image in any stage. The binary forms of medical images are normally produced by simple segmentation techniques such as thresholding. They contain foreground objects surrounded by background regions. Some times a set of background regions lying completely within the foreground regions due to imperfection in the binary conversion identified by the optimal thresholding. It is known as holes within the foreground objects or Region of Interest (ROI).

In this paper we propose an algorithm for filling holes that appear within the binary brain mask. The proposed approach is based on Run Length Encoded Data (RLED) of binary image and region labeling procedure. The proposed method is fully automatic and no user intervention is required at any stage. It is best suited for medical image analysis process where the scanned organs are completely surrounded by air.
in the form of dark background. Using this expert knowledge, the other regions corresponding to background within objects (holes) are identified and removed using the RLED and region labeling process. For continuity, we first give a brief outline of the existing hole filling methods.

II. METHODS

A. Areafill Operation

It is a simple and an efficient method. This method initially calculates the area (in pixels) of each dark/white region. Next it will check the area of dark region with a threshold value. If the area is less than the threshold value they will be treated as holes. Then the dark holes will be removed by changing their intensity into light/white color. The threshold value is a user defined term and its computation depends upon the type of applications or images used. Geng et al. developed a hole filling algorithm for segmentation of worm body [2]. They defined the dark regions that have compactness (defined as perimeter/area) greater than 25 as holes. This compactness was used to avoid filling large exterior holes (> 100 pixels) that are formed by severe warm body bending.

In Fig. 1(a), binary form of a MRI head scan is given. In this image the foreground objects, brain and scalp are in white color. The regions in black color within brain are here treated as holes. Black regions having area within 100 pixels are treated as holes and filled as shown in Fig. 1(b). For area less than 500 pixels is shown in Fig.1(c). In both cases larger holes are left unfilled.

B. Morphological Close Operation

Morphological closing is one of the easiest methods that can be applied with the selected ROI to fill holes [3]. Morphological transformation and operations are discussed in Appendix A. A closing routine, consisting of a dilation followed by erosion, will close off some holes that occur within the brain volume. Further it will fill small pits in the surface and thus smooth the surface. This is done by using an octagonal Structuring Element (SE) \( O_4 \) that has a diameter of 9 voxels in BSE (brain surface extraction) method developed by Shattuck et al. [4]. \( O_4 \) approximates a sphere in 3D, and closing with this element will remove any surface pits and fill any holes that have diameter of 9 voxels or less. Therefore, this closing operation will result in a brain volume in which boundaries are smooth and all holes less than nine voxels wide are close. Fig. 1(d) shows the result of holes filling done by this close operation on Fig. 1(a).

Two more methods, semi-automatic and automatic using set of morphological operations are explained by Gonzalez and Woods [7]. Morphological dilation plays main role in these sets. The accuracy of the output of these methods is controlled by the size and shape of the SE chosen for the dilation operation.

In morphological operations, the success depends on the hole size. Large holes require large structuring elements that also have a considerable and often unwanted smoothing effect. Another unwanted effect of large structuring elements is the increase in computation time [3].

C. Floodfill Operation

This operation starts from a specified interior point \((x, y)\) and reassign all pixel values until reaches the object boundary [6]. For binary images, this operation changes connected background pixels to foreground pixels, stopping when it reaches object boundaries.

There are two methods for proceeding to neighboring pixels from the current test position. They are 4-connected and 8-connected methods. In 4-connected method, the four neighboring points are tested. These are the pixel positions that are right, left, above and below the current pixel. The procedure for 4-connected method developed by Hearn and Baker [6] is given in Appendix B. The floodfill procedure flood fills a 4-connected region recursively, starting from the input position \((x, y)\). This procedure can be processed either from inside the object or from outside the object i.e., background. But user intervention is required to select the seed point (input position). If it starts within the holes then the old color is replaced by fillcolor until reaches the object boundary. This method detects and fills the holes one by one in pixel wise. 4-connected procedure sometimes leads to partial filling in narrow holes [6] while processing from inside the holes. A matrix of intensity values of a portion of an image is given in Fig. 2(a) in which, the hole (binary 1’s) is completely surrounded by foreground object (binary 0’s). Instead of one it is considered to be 4 regions by the 4-connected procedure as shown in Fig. 2(b). So an 8-connected operation was introduced, in which the diagonal pixels also included for testing and detecting them correctly as shown in Fig. 2(c). Hence 8-connected filling procedure would correctly fill any form of holes.

An alternative procedure for filling holes using this n-connected concept is given [5]. This procedure assumed that the foreground object is completely surrounded by background. The algorithm for this procedure is:

1. Take the complement of binary image.
2. Select a seed point from background.
3. Apply the floodFill procedure until reaches the object boundary or image limit.
4. At the end only the holes (white in color) will be there in the image.
5. Remove them from the binary image using proper image processing operations.

This method first finds all the holes and then removes them from the binary image. This procedure is applicable to images with background, a largest and a single connected component around object. For other cases one has to select a seed point to each background region and repeat the steps 1–3 for each background region.
The proposed method is based on the labeling process using Run Length Encoded Data (RLED). The labeling process using run length encoded data is given in Appendix C. The procedure used in our method is:

1. Find and label the regions corresponding to background intensity.
2. Separate the regions belonging to either background or holes based on the following condition.
   
   In each region, the ends of runs are checked for image limit. If a run ends with image limit then the entire region will be marked as a background. Otherwise it is marked as a hole.

3. Repeat step 2 for all the detected regions that are having intensity equal to background.
4. Change the intensity of regions that are marked as holes to foreground intensity (hole filling).

The holes detected by our proposed method is given in Fig. 3(b) and the hole filled image is given in Fig. 3(c).

### IV. RESULTS AND DISCUSSIONS

MRI scans taken from medical image websites and collected from KGS Advanced MR & CT Scan, Madurai, Tamilnadu, India are used for validating the methods. An example for qualitative validation is shown in Fig. 4. A binary form of MRI axial scan shown in Fig. 4(a) is taken for experiment. For Areafill operation the threshold value for hole area is fixed to 25 pixels and the result of it is shown in Fig. 4(b). Two holes whose area is greater than 25 are left over within the image. In Areafill operation, user intervention is required to select the threshold value. User should have the application specific knowledge to set the threshold value for filling the holes areas. Fig. 4(c) shows the results of morphological close operation performed by a square type SE of size 3. Here also the holes larger than the SE are left over. The performance of fill operation depends on the selection of SE. Any hole less than the size of SE are left over. If the size of SE increased then the brain surface will be smoothed excessively as shown in Fig. 4(c). Flood Fill and proposed methods have similar effects as shown in Fig. 4(d) and (e). One of the major drawbacks of FloodFill operation is its space complexity because it requires considerable stacking of neighboring points. It is a time consuming process since every neighbor of current pixel is tested for filling even though they are processed recently. But our method can fill holes of any size. Hole detection is very easy using labeling process and RLED. Stacking of neighboring pixels is not required and just starting point, length and label of run alone stored.
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Fig. 3: Proposed method (a) Binary form of MRI axial head scan (b) Holes detected by proposed method (c) Hole filled image.

Table 1: Performance Comparison of Existing and Proposed Methods

<table>
<thead>
<tr>
<th>Items</th>
<th>AreaFill Operation</th>
<th>Morphological Operation</th>
<th>FloodFill Operation</th>
<th>Proposed Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance</td>
<td>Semi automatic (depends on selection of threshold value)</td>
<td>Semi automatic (depends on selection of SE)</td>
<td>Semi automatic (depends on seed point)</td>
<td>Fully Automatic</td>
</tr>
<tr>
<td>Data structure required</td>
<td>• Two arrays, one for background region and another for foreground region • Threshold value</td>
<td>• Image array • SE array</td>
<td>• Image array • Stack of neighboring pixels</td>
<td>• Two arrays, one for background region and another for foreground region</td>
</tr>
<tr>
<td>Application</td>
<td>General images</td>
<td>General images</td>
<td>General images</td>
<td>Medical images</td>
</tr>
<tr>
<td>Processing Time</td>
<td>More</td>
<td>More</td>
<td>More</td>
<td>Less</td>
</tr>
</tbody>
</table>

For measuring the processing time all these methods were developed and run in a 1.73 GHz Intel Pentium dual-core processor, Windows XP with 1GB RAM using Matlab 6.5. Processing time of proposed method is less than that for other existing methods and comparable to 8-connected FloodFill operation. The performance comparison of AreaFill, Morphological, Floodfill and proposed methods is given in Table 1.

V. CONCLUSION

In this work we have proposed a new method for filling holes in medical image processing using RLED of regions. Experimental results on a binary MRI head scan image shows that the proposed method performs better than the existing hole filling methods Areafill, morphological and Floodfill. The three existing operations Areafill, morphological and Floodfill operations are require user intervention to run the process. The user intervention is application oriented and subject specific knowledge is required. But the proposed method is fully automatic. It is applicable to images in which the foreground objects are completely surrounded by background region. The proposed method could be used as a stand alone module in medical image processing pipeline for filling the holes.

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In digital image processing, morphological operations preserve the basic properties of object while removing irrelevant features. Morphological techniques typically probe an image with a small shape or template known as a Structuring Element (SE). The SE is positioned at all possible locations in the image and it is compared with the corresponding neighborhood of pixels. Morphological operations differ in how they carry out the comparison. Some test whether the structuring element ‘fits’ within the neighborhood; others test whether it ‘hits’ or ‘intersects’ the neighborhood.

A Structuring Element (SE) is said to fit an image if for each of its pixels that is set to 1, the corresponding image pixel is also 1. The SE pixels that are 0 define points where the corresponding image value is irrelevant. The SE is said to hit an image if for any of its pixels that is set to 1, the corresponding image pixel is also 1. We also ignore image pixels for which the corresponding SE pixel is 0. The SE will be small compared to the image.

The main morphological operations are dilation and erosion. A morphological transformation \( \psi \) is given by the relation of the image (point set \( X \)) with another small point set \( B \) called STE. \( B \) is expressed with respect to a local origin \( \sigma \), called the representative point. To apply the morphological transformation \( \psi(X) \) to the image \( X \) means that the structuring element \( B \) is moved systematically across the entire image. Assume that \( B \) is positioned at some point in the image; the pixel in the image corresponding to the representative point \( \sigma \) of the structuring element is called the current pixel. The result of relation (which can be either zero or one) between the image \( X \) and the structuring element \( B \) in the current position is stored in the output image in the current image pixel position.

Dilation \( \oplus \) combines two sets using vector addition or Minkowski set addition.

\[
X \oplus B = \{ p \in \mathbb{E}^2 : p = x + b, x \in X \text{ and } b \in B \}
\]

where \( p \) is the point sets of the Euclidean 2D space \( \mathbb{E}^2 \).

Dilation is the point set of all possible vector additions of pairs of elements, one from each of the sets \( X \) and \( B \). It grows a layer, defined by \( B \), onto the boundary of image objects in binary image. It increases the size of the object image.

Erosion combines two sets using vector subtraction of set elements.

\[
X \ominus B = \{ p \in \mathbb{E}^2 : p + b \in X \text{ for every } b \in B \}
\]

For every pixel, \( B \) must be present in the image. If so, the pixel will be preserved. Otherwise it will be removed. Thus it peels away a layer of points at the boundary of the binary image. It is used to simplify the structure of an object. It might thus decompose complicated objects into several simpler ones. It is the dual operator of dilation.

\[
(X \ominus B) \oplus B = X \ominus (B \ominus B)
\]

Dilation operation is commutative and also associative. Erosion, in contrast to dilation, is not commutative. Neither erosion nor dilation is an invertible transformation. An essential part of morphological operations is the SE. SE is a matrix consisting of only 0’s and 1’s that can have any arbitrary shape and size. The pixels with values of 1 define the neighborhood. The size of SE should be always smaller than the image being processed.

Most of the other morphological operations are modified dilation or erosion, or combinations of dilation and erosion. Morphological open and close are such operations. Erosion followed by dilation is known as morphological open operation. Usually open operation smoothes contours, suppress small islands and sharp caps of images. Morphological close is nothing else but dilation followed by erosion. It blocks up narrow channels and thin lakes.
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APPENDIX–B

Void floodFill4 (int x, int y, int fillColor, int oldColor)
{
    If (getPixel (x,y) == oldColor)
    {
        setColor (fillColor);
        setPixel (x,y);
        floodFill4(x+1, y, fillColor, oldColor);
        floodFill4(x-1, y, fillColor, oldColor);
        floodFill4(x, y+1, fillColor, oldColor);
        floodFill4(x, y-1, fillColor, oldColor);
    }
}

APPENDIX–C

One of the methods for region identification is to label each region with a unique number. Such identification is called labeling or coloring [1]. Input to a labeling algorithm is usually either a binary or multi-level image where background may be represented by zero valued pixels, and objects by non-zero values. Output will be the labeled regions of the desired intensity, either background or object.

Region labeling using run length encoded data is simple and fast. This algorithm has two passes. In first pass, the runs are analyzed for neighborhood and labeled in row-wise. The label collision problem realized in first pass is solved by second pass. The algorithm [1] has the following steps.

1. First pass: Use a new label for each continuous run in the first image row that is not part of the background.
2. For the second and subsequent rows, compare the positions of runs.
   (a) If a run in a row does not neighbor (in the 4- or 8-sense) any run in the previous row, assign a new label.
   (b) If a run neighbor precisely one run in the previous row, assign its label to the new run.
   (c) If the new run neighbors more than one run in the previous row, a label collision has occurred.
       (Collision information is stored in an equivalence table, and the new run is labeled using the label of any one of its neighbors).
3. Second pass: Search the image row by row and re-label the image according to the equivalence table information.