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IMPLEMENTATION OF WATERSHED IMAGE SEGMENTATION FOR IMAGE PROCESSING APPLICATIONS

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Abstract: The watershed algorithm based on connected components is selected for the implementation, as it exhibits least computational complexity, good segmentation quality and can be implemented in the FPGA. It has simplified memory access compared to all other watershed based image segmentation algorithms. This paper proposes a new hardware implementation of the selected watershed algorithm. The main aim of the paper is to implement image segmentation algorithm in a FPGA which requires minimum hardware resources, low execution time and is suitable for use in real time applications.

Keywords : Image segmentation, watershed, connected component, FPGA

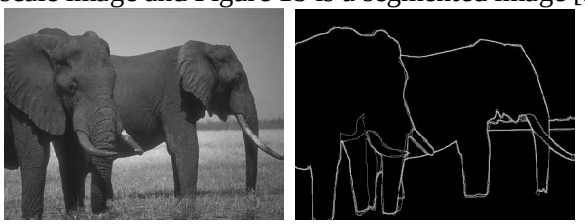
INTRODUCTION

Image segmentation is process of partitioning the image into multiple segments. It is first important step in many image processing applications like image analysis, image description and recognition, image visualization and object based image compression.
Image segmentation means assigning a label to each pixel in the image such that pixels with same labels share common visual characteristics. It makes an image easier to analyze in the image processing tasks. There are many different techniques available to perform image segmentation. The algorithm used in this paper is watershed based image segmentation. It is a hybrid technique because it is the result of threshold based, edge and region based techniques using morphological watershed transform. The watershed transformation [1] is popular image segmentation technique for gray scale images. An efficient watershed algorithm based on connected components [2] shows very good results compare to other watershed based image segmentation algorithms.

In connected components based watershed image segmentation algorithm, image is scanned from top left to bottom right and from bottom right to top left. During each scan, unique labels are given to each detected regional minima. If the labels have already been given to their neighbor pixels during previous scan then those labels are copied to the pixels. Finally each component (pixel) is connected to its local minima and all components connected to same local minima make a segment.
Watershed based image segmentation produces over-segmentation based on different properties of the image. In this paper, pre-processing of the image before image segmentation is considered to reduce the over-segmentation problem of watershed based image segmentation.

IMAGE SEGMENTATION

Image segmentation means division of an image into meaningful structures. It is process of extracting and representing information from the image to group pixels together with region of similarity [8]. Sonka et al. define the goal of segmentation as “to divide an image into parts that have a strong correlation with objects or areas of the real world contained in the image" [6]. Figure 1 shows a basic example of the image segmentation where Fig 1a is an original gray scale image and Figure 1b is a segmented image [9].



(a) Original image (b) Segmented image
Fig 1.: Image segmentation

All the objects of the original image can be identified in segmented image with their boundaries. There are many techniques available for the image

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segmentation. Examples are, threshold based segmentation, edge based segmentation, region based segmentation, clustering based image segmentation, markov random field based segmentation and hybrid techniques. These segmentation methods differ from their computation complexity and segmentation quality. The main aim is to find a segmentation algorithm which is feasible to implement in hard-ware with the minima use of hardware resources (slices/gates), gives best segmentation quality and has possibility to be used for real time image processing applications.

WATERSHED BASED IMAGE SGMENTATION

Watershed transformation also called, as watershed method is a powerful mathematical morphological tool for the image segmentation. It is more popular in the fields like biomedical and medical image processing, and computer vision [3]. In geography, watershed means the ridge that divides areas drained by different river systems. If image is viewed as geological landscape, the watershed lines determines boundaries which separates image regions. The watershed transform computes catchment basins and ridgelines (also known as watershed lines), where catchment basins corresponding to image regions and ridgelines relating to region boundaries [4]. Segmentation by watershed embodies many of the concepts of the three techniques such as threshold based, edge based and region based segmentation.

Watershed algorithms based on watershed transformation have mainly two classes. The first class contains the flooding based watershed algorithms and it is a traditional approach where as the second class contains rainfalling based watershed algorithms.

Many algorithms have been proposed in both classes but connected components based watershed algorithm [2] shows very good performance compared to all others. It comes

under the rainfalling based watershed algorithm approach. It gives very good segmentation results, and meets the criteria of less computational complexity for hardware implementation.

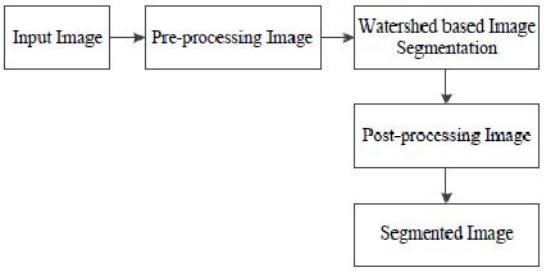
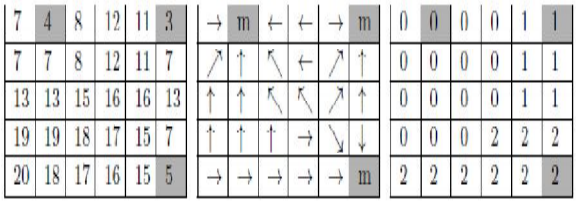


Fig 2.: Block diagram of watershed based image segmentation

There are mainly three stages as indicated by Fig 2 for watershed based image segmentation approach. First stage is defined as pre-processing, second stage as watershed based image segmentation and last stage as post-processing. Input image is first processed by the pre-processing stage, and then given to watershed based segmentation stage. The resulting image is post processed by the final stage to get a segmented image. Pre-processing and post-processing are necessary to overcome the problem of over-segmentation in watershed based image segmentation.

WATERSHED BASED ON CONNECTED COMPONENT

The basic concept of connected components based algorithm is explained by Fig 3. The original 6 x 6 image has three local minimum values indicated by gray boxes. If the component (pixel) is not a local minimum then it is connected to its lowest neighbours as shown by arrows in Fig 3b, where m indicates a local minimum. All components directed towards the same local minimum make a segment and are given a same label value in Fig 3c.



(a) The original image
(b) Each pixel connect to lowest Minimum
(c) The Image with labels

Fig 3.: Basic concept of connected components approach

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PRE-PROCESSING STAGE

The watershed based image segmentation produces mostly an over-segmentation of the image. Pre-processing and post-processing of an image is performed to overcome this problem. Pre-processing is mainly applied to the image before the watershed segmentation. As shown in Fig 4, pre-processing includes first stage of noise removal using median filter, second stage of morphological gradient calculation and last stage of thresholding a gradient image.

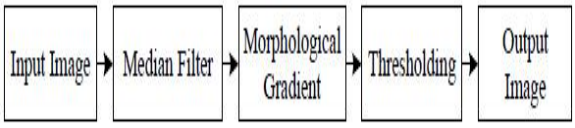

Fig 4 : Block diagram of pre-processing stage

A. Median Filter

Impulse noise is most common noise in image processing. It generally occurs due to malfunctioning pixels in camera sensors, faulty memory location in hardware or error in data transmission [7]. There are mainly two types of impulse noise, one is the salt and pepper noise (also known as speckle noise) and second is the random value shot noise. Noisy pixel only takes maximum or minimum values in case of salt and pepper noise where as it takes arbitrary value in case of random value shot noise.
Median filter, also known as an edge preserving non linear filter is a simple and effective method to remove impulse noise. Median filter considers each pixel in the image and checks its nearby neighbour pixel to decide either it is representative of its neighbourhood pixels. It replaces pixel value with the median of the neighbourhood pixels. It is calculated by numerical shorting of all neighbourhood values and replace considered pixel with the middle value of nine sorted values.
Median filter is more effective and robust than mean or average filter because a single unrepresentative pixel value in neighbourhood affects very less to the median value. Median filter gives one of a neighbour value as an output pixel and hence it does not create new unrealistic values near the edges and preserves sharp edges. It is mathematically expensive to calculate the median value because it requires sorting of nine values for each pixel.

B. Morphological Gradient

The morphological gradient is a powerful tool for an edge detection. At the second stage of the pre-processing, the morphological gradient of the filtered image is computed to overcome over-segmentation problem. When the morphological transition is applied to the gray scale image, it returns to high values when sudden transitions in gray level values (along the object edges) are detected, and returns to low values if neighbourhood pixels are similar. The Watershed transform is then applied to the gradient image so that boundaries of the catchment basin could be located on high gradient points. This operator can perform well only when noise level is effectively reduced before it is applied.
The morphological gradient is calculated by taking 3 x 3 neighbourhood window of the given pixel, then the difference between the maximum (dilation) and minimum (erosion) gray level value of the neighbourhood is calculated [5]. Calculated gradient value is rounded to the nearest integer.

C. Sorting Networks

Sorting networks (SN) are used to sort the numbers. For median filter and morphological gradient calculation, nine values sorting network is necessary. Sorting network is defined as a network of elementary operations denoted as compare&swap(CS) or comparators that sort all the elements [7]. As an example, two elements p and q are compared and exchanged if necessary for sorting sequence. Number of elements decide requirement of total number of comparators in SN.
The selection of sorting network is mainly considered for FPGA implementation. There are mainly two important criteria that needs to be considered, one is requirements of hardware resources and another one is latency. Latency of SN means the numbers sequential execution of number of CS operations, and requirement of hardware resources means number of comparators and registers required for sorting given number of elements.
Bitonic SN and odd-even merge sort are tow best sorting networks fulfil required criteria for the hardware implementation. For sorting nine elements, both of them use nearly same hardware resources and have a same computation latency [7].

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D. Thresholding

The classical approach to get an edge image is to threshold the gradient image. The main objective of third stage in the pre-processing is to reduce the over-segmentation as much as possible. The threshold value is set for the local minimum to prevent creation of large number of catchment basins. In this stage, all the gradient values lower than this threshold value are set as a local minimum and watershed starts from this local minimum. Thresholding also removes small variations within the homogeneous region. It is not easy to find an appropriate threshold value for each respective image.

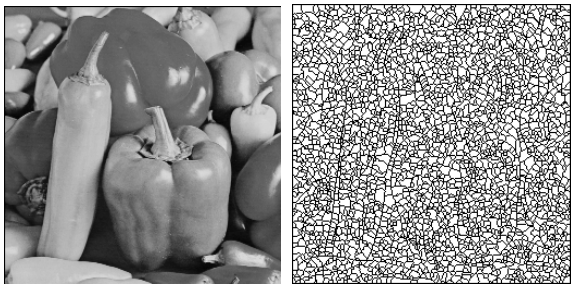
If the threshold value is very low then edges become very wide and if the threshold value is too high then edges may not be detected. The optimal threshold value can be selected by iterative method for connected components based watershed image segmentation. First some initial low threshold value is selected, and check the number of labels used by algorithm, and visualize the image segmentation results and then threshold value is iterated for the optimal result. The number of labels are used by the algorithm depends on number of segments in the image. Number of segments can be controlled by varying the threshold value and optimum segmentation result can be obtained. For thresholding a given image, all the gradient values of the image pixels are divided by the threshold value, so all the values lower than the threshold value become zero and other values are scaled down relative to the threshold value.

POST-PROCESSING STAGE

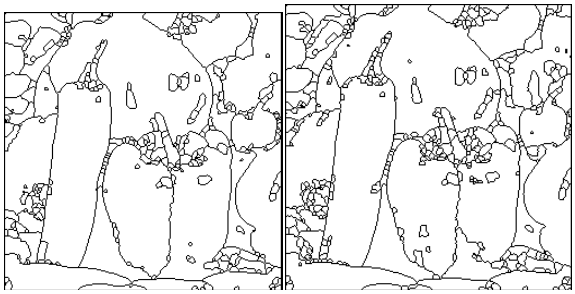
The segmented image still has some over-segmentation after the pre-processing and segmentation. Small segments can be merged using different rules to increase the segmentation quality. The region merging method [5] is used for post processing which is developed by Haris et al. Post processing stage is not used in this thesis for hardware implementation and only short description is given in this section.

RESULTS AND CONCLUSION

Connected components based watershed image segmentation algorithm gives over-segmentation without using the pre-processing stage. Watershed based image segmentation is only applied to the gradient image. Original pepper image is converted to the gradient image which is segmented without applying median filter and thresholding, and output image is over-segmented as shown in Fig 5b.



(a) Original image (256 x 256)
(b) Segmentation of gradient image without median filter and thresholding



(c) Segmented image (Threshold=12)
(d) Segmented image (Threshold=14)

Fig 5: Segmentation results with different threshold values for pepper image (256x 256)

A watershed algorithm based on connected components is selected for the implementation, because it has simplified memory access, least computational complexity and good segmentation results compared to the other image segmentation algorithms. A pre-processing step is required to overcome the problem of over-segmentation by watershed based image segmentation.

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