

An Implementation of Watershed Based Image Segmentation Algorithm Using FPGA Processor

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Abstract: In this work, the watershed algorithm is used as a method in solving the image segmentation problem. However, of the many variants of the watershed algorithm not all are equally well suited for hardware implementation. Different algorithms are suited and 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 FPGA. Mostly the watershed segmentation result in over-segmentation. The markers based watershed segmentation transformation is proposed in this project. The proposed method reduces noise and over-segmentation. It has simplified memory access compared to all other watershed based image segmentation algorithms. The main aim of this project 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: segmentation, project, image, processor, algorithm

1. 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. The algorithm used in this project 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. Watershed algorithm is a region based segmentation algorithm. The basic concept of watershed algorithm is used to find the watershed lines containing regional minima. It defines the peak forming the limit between two catchment basins and the intercepting points constitute Watershed. The main drawback of watershed segmentation is over-segmentation, presence of noise, time consuming. This can be removed easily using marker controlled watershed segmentation. A marker is a connected component belonging to an image. The markers include the internal markers, associated with objects of interest, and the external markers, associated with the background.

2. Digital Image Processing

Classical image processing techniques [1] when applied in segmentation tasks present the difficulty that borders are left normally open (what we need are closed contours). Another problem is that distinct objects in the scene are assumed as a single object in the image (i.e., classical techniques have troubles identifying touching objects as separate entities). Those problems are compounded by noisy images, by uneven illumination, and by overlapping. Figure 1 illustrates some of the problems with classical image processing techniques. Fig. 1(a) shows a scene where the two rocks at the bottom left are touching. Conventional thresholding produces the image in Fig. 1(b), whereas a well-known edge operator produces the image in Fig. 1(c).

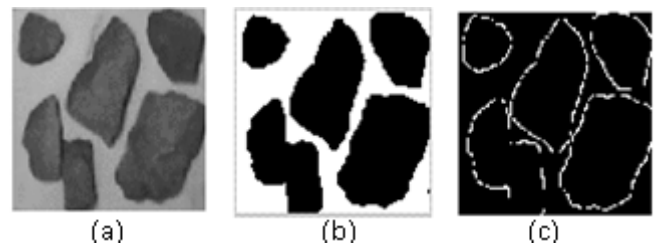


Figure 1: (a) Gray level image, (b) Thresholding with a global value of 120, (c) Edges detected using Sobel masks

3. The Watershed Transformation

The Watershed Transformation, also known as the lines dividing waters is a powerful tool for image segmentation. The basic idea consists of segmenting images by simulating flooding on a topographic surface. Drilling a hole at each local minimum performs this process and then slowly submerging the entire surface into a lake. The water level will rise continuously. Then, in order to avoiding that water coming from different holes merge, a dam is built at each point of contact. At the end of the process, the union of all those dams constitutes the watersheds. Unfortunately, this transformation usually produces an over segmentation of the image. To deal with this problem, proposed a strategy based on controlled marks. This approach is based on the idea that a machine vision system knows from other sources the location of the objects to be segmented. Therefore, before segmentation we must indicate which objects are to be segmented and which one is the background. The success of the segmentation is dependent upon the quality of the controlled marks that we produce

3.1 Fundamentals

Let us consider a gray level image $f(x,y)$ as a topographic surface S , where each gray level can be seen as terrain elevation, and where hills correspond to clear regions and where valleys or basins possess a single minimum. Suppose that each minimum $m_i(f)$ is perforated and that we introduce S vertically into a lake, assuming constant speed of descent.

Water will pass through the holes flooding the surface. During this flooding, water coming from two or more minima (hence belonging to different basins) may collide. This event is to be avoided so, dams are built at the points where these waters can join. At the end of this process, only those dams shall be visible from above. These dams separate different basins $C_i(f)$, each containing a single minimum $m_i(f)$. Figure 2 shows an example with two minima associated to two basins. The red zone represents the dam built to avoid that the water coming from adjacent basins join.

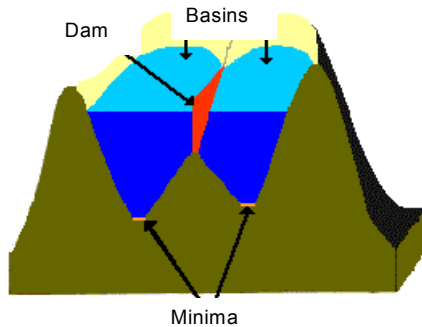


Figure 2: Flooding of the topographic surface and construction of the dam.

3.2 Algorithm

Let us imagine a vertical cut (cross section) through a topographical surface along the x-axis. The result will be a 1-dimensional function similar to that shown in Figure 3. In this figure, the vertical axis corresponds to gray level, the horizontal axis corresponds to position along the x-axis, and the areas of lower intensity correspond to valleys. Let us also define $\max = n+1$, where n is the maximum gray level. In figure 3, $n = 3$, and $\max = 3$.

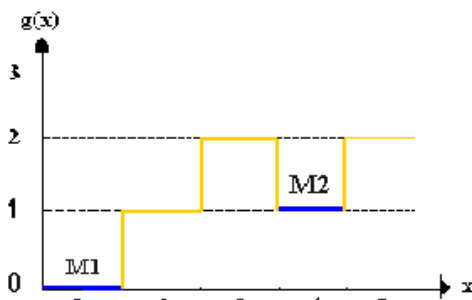


Figure 3: One-dimensional representation of a function with three gray levels (0, 1, 2).

This way, Figure 3 is composed of three well-defined regions:

- Set of pixels belonging to regional minima (in blue)
- Set of pixels in which a drop of water shall slide towards a single minimum (in brown). For a given minimum, this set of pixels is called basin.
- Set of pixels in which a drop of water could fall into more than one basin. The points satisfying this condition form the crest line of the surface and are called watershed lines (in red in Fig. 4).

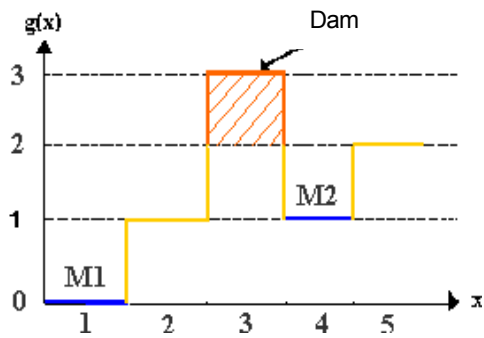


Figure 4: Building the dams

Considering again Fig. 3, we shall describe the process of dam construction. Flooding will be simulated by incrementing gray level values from 0 to max in unit steps. This way, water will penetrate from the minima M1 and M2 and will begin flooding the image. Nothing special can be said for the first two steps (gray levels 1 and 2, respectively). However, as soon as the flooding level as reached level 3 and for the particular point $x=3$, then those waters associated with M1 will become in contact with waters associated with M2. To avoid that contact from taking place, we build a dam at this location (in red in Figure 4). The algorithm is programmed to stop when flooding reaches level $\max=3$.

4. Proposed Methodology

The approaches for marker based watershed image segmentation of images have been implemented to overcome the problem of over-segmentation and under-segmentation. The methods involved:

- Region growing using DIS maps
- Watershed Segmentation using Edge Markers

4.1 Region Growing Using Dis Map

This scheme consists of two major steps:

1. Stage of Edge Detection
2. Stage of Region Growing

4.1.1 Stage of Edge Detection

At this stage a 3X3 running window runs pixel by pixel on the input image and the DIS for the center pixel is defined. Thus at this stage, DIS maps are computed using a 3X3 window which is made to run pixel by pixel on an input image. The small DIS values indicates smooth regions on the other greater DIS values represent that pixel is on the area that changes severely in gray levels. The DIS for center pixel in is calculated as

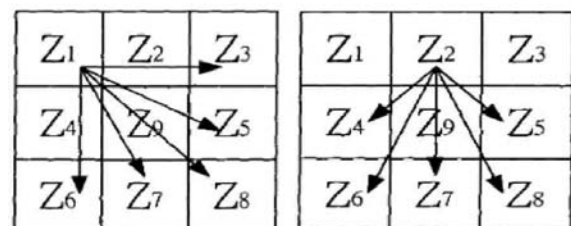


Figure 5: DIS windows

The following algorithm is used to perform edge detection
BEGIN

Run 3X3 window (DIS detecting window) pixel by pixel over an entire image
Define the DIS for the center pixel and compute the DIS map
END

4.1.2. Stage of Region Growing

The stage of region growing groups pixels or sub regions into larger regions based on predefined criteria for growth. The syntax for the function to do basic region growing is

$[g, NR, SI, TI] = \text{regiongrow}(f, S, T)$

Where, f is an image to be segmented and parameter S, T is an array or a scalar. Parameter NR is the number of different regions. Parameter SI is an image containing the seed points and parameter TI is an image containing the pixels that passed the threshold test before they were processed for connectivity.

The following algorithm is used to perform region growing:

BEGIN

- Choose an unprocessed pixel that has a smallest DIS value on map as R .
- Check each of the 4 neighboring pixel of R to see if it is unlabeled. If yes edit to the candidate list. If none has been added assign the label of a neighboring pixel which has the gray level closest to R , then go to END.
- Choose the pixel in the candidate list that has a smallest DIS value as a new reference pixel R .
- Check all neighboring pixel of R to see if they are edge pixel, label them as P BOUNDARY.
- Check if R is an edge pixel. If so, label it as P BOUNDARY. If candidate list is not empty, go to Step 3.
- Add 4 neighbors of R that has not been processed to the candidate list. Label R as P REGION. If the candidate list is not empty go to Step 3.

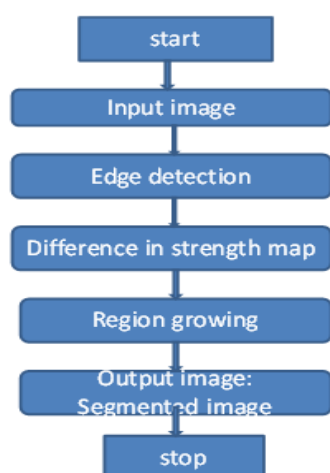


Figure 6: Region Growing Using DIS Map

4.2 Watershed Segmentation Using Markers

A marker is a connected component belonging to an image. The markers include the internal markers, associated with objects of interest, and the external markers, associated with the background. The definitions of an internal marker is

- A region that is surrounded by points of higher “altitude”.
- The points in the region form a connected component.

- All the points in the connected component have the same intensity value.

5. Experimental Results

The watershed algorithm was tested on many scenes, and three general cases are to be shown. It should be emphasized that the marks were obtained through a series of steps involving: thresholding, morphological gradient, morphological dilation and erosion, among others. These operations allowed for improved detection of shadows between adjacent rocks.

Further optimization can be achieved allowing interactive selection of marks. This way, increasing the number of marks will reduce the risk of missing boundaries, meanwhile, on the other hand, selecting less marks will reduce the risk of false edge detection. To achieve improved results, it is more convenient to deal with the morphological gradient as input image rather than the original image. (Figure 6(a)). This gradient is a tool from morphological mathematics, defined as: the difference between the dilation of f minus the erosion of f , under the same structuring element or set B .

$$g = (f \oplus B) - (f \ominus B)$$

The gradient image is shown in Figure 4(b) where the image boundaries have the highest altitudes.



Figure 7(a): Original Image



Figure 7(b): Morphological gradient of (a)

According to the watershed criteria, flooding shall begin from the image minima obtained after applying morphological gradient. Figure 7 (c), shows regional minima of Fig. 7(b). When applying watershed transformation, water shall flood the topographical surface from all minima. At the end of this process, we obtain the image shown in Fig. 7(d).



Figure 7(c): Topographical Image



Figure 7(d): Watershed boundaries obtained when applying regional minima

The watershed segmentation process has too many basins, leading to an over segmented result (Fig. 7(d)). Each one of these basins corresponds to a minimum of the morphological gradient. These minima are produced by small variations, mainly due to noise, over the gray level values. This over segmentation could be partially overcome employing proper filtering. However, a much-improved result can be obtained if we can impose a mark for each object as well as the background. Waters shall flood the topographical surface from the marks and shall generate as many basins as marks may exist. This way, we can solve the over segmentation problem. Figure 7(f) shows the improved results when using marks after thresholding. Especially important is the fact that the two rocks that are touching in the scene appear now as two separate objects as shown in figure 7(g) containing local minima regions in the segmented image.



Figure 7(e): Distance transformation

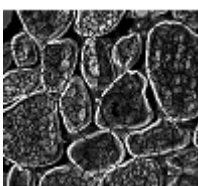


Figure 7(f): Thresholding



Figure 7(g): Watershed segmentation containing local minima regions

6. Conclusions and Future Work

It has been show that good segmentation results can be achieved. Watershed algorithm is a powerful and fairly efficient tool for image segmentation, even for overlapping or adjacent rocks. These tools, when combined with the process of mark selection, permit an effective approach for practical image segmentation. The success of this combined procedure is however, dependent upon the process of mark selection.

The future works includes modeling the process in VHDL, and synthesized under the XILINX ISE8.2i system. Hardware implementation offers the advantage of speeding up processing. In this project, we are interested in a co-design of watershed based segmentation system, making use of the potential software in FPGA Processor, enabled by the embedded processor power Pc.

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