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An Enhancement of Image Segmentation Using Modified Watershed Algorithm

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Abstract

In this paper, we propose a watershed algorithm that applies a high-frequency enhancement filter to emphasize the boundary and a local adaptive threshold to search for minimum points. The previous method causes the problem of over-segmentation, and over- segmentation appears around the boundary of the object, creating an inaccurate boundary of the region. The proposed method applies a high-frequency enhancement filter that emphasizes the high-frequency region while preserving the low-frequency region, and performs a minimum point search to consider local characteristics. When merging regions, a fixed threshold is applied. As a result of the experiment, the proposed method reduced the number of segmented regions by about 58% while preserving the boundaries of the regions compared to when high frequency emphasis filters were not used.

Keywords: *Image Segmentation, Watershed Algorithm, Over-Segmentation, Boundary Preservation*

1. Introduction

The purpose of image segmentation is to divide an image into regions having certain properties. In addition, it refers to extracting objects that have a strong correlation with real objects or regions in an image. The segmented image is used in face and object recognition, and is also used in security, autonomous driving, and image retrival systems. Algorithms used for such image segmentation are classified into threshold-based, boundary-based, region-based, blended, and interactive image segmentation.[1]

The threshold-based image segmentation algorithm is a method of classifying pixels of an image after determining a threshold value suitable for a region to be segmented. Boundary-based image segmentation is a method of extracting regions using a boundary detection algorithm. Since these two methods can bring different segmentation results depending on the value and number of thresholds, long-term simulations are required to obtain appropriate thresholds.

Region-based image segmentation methods include splitting, merging, and region growing methods. Mixed image segmentation is a method that combines boundary -based image segmentation and region-based image segmentation methods, and has two algorithms. This combines the characteristics of the two algorithms to predict more accurate results.[2, 3] The interactive image segmentation method is a method in which a user inputs information and segments an image by interaction between a computer and a user.[4]

An image segmentation method widely used in region-based search is the watershed algorithm. The watershed algorithm merges regions while gradually filling in water from the minimum region by setting the

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gradient value of the image as the height. Finally, a part surrounded by one boundary is determined to be a uniform region.[5] The watershed algorithm was introduced by Lantuejoul. Soille presented an algorithm that uses sequential and parallel computation methods for fast processing.[6]

Several watershed methods show over-segmentation with many local minima, resulting in segmentation with inaccurate boundaries.[7] A method of merging segmented regions has been proposed as a method to reduce this over-segmentation problem. This method reduces over-segmentation, but increases processing time and results in inaccurate image segmentation.

In this paper, we determine local minimum point based on high-frequency enhancement filtered images to reduce over- segmentation and for image segmentation with accurate boundaries.

2. Linear spatial domain filtering and watershed algorithm

Spatial frequency refers to the number of repetitions of the same pixel value or color in unit space. A high frequency means a place where the brightness change is fast or a color change is rapid, and a low frequency means a place where the brightness change is slow or the color change is small. Spatial filtering is a filter process that removes or emphasizes a spatial frequency band in an image, and includes a low-pass filter (LPF) and a high-pass filter (HPF). A low-pass filter is a filter that passes low-frequency components and blocks high-frequency components, and is mainly used to remove noise or obtain blurry images. The high-pass filter is a filter that passes high-frequency components and blocks low-frequency components, and can improve a blurred image to obtain an image result in which a clear boundary is revealed. Figure 1 shows the low-pass filter and high-pass filter mask. Since the sum of the high-pass filter mask is 0, the mask response is close to 0 in the constant or slowly changing brightness region.

1/9	1/9	1/9
1/9	1/9	1/9
1/9	1/9	1/9

(a) LPF

-1/9	-1/9	-1/9
-1/9	8/9	-1/9
-1/9	-1/9	-1/9

(b) HPF

Figure 1. Filter Mask

The watershed algorithm sees the spatial gradient of the image as a topographical surface, drills a hole in each local minimum on the topographical surface, and develops the process of catchment basin. When two catchment basins growing in the process meet at the watershed, a boundary point is set up to create a boundary point. The continuum becomes the boundary dividing the catchment basin. Every local minima has an independent region, and the boundary between regions is determined by the watershed. Figure 2 shows the watershed algorithm, and figure 3 shows the image segmentation method using the watershed algorithm. After simplifying the input image and obtaining the gradient image, in order to segment the region from the gradient image, it is processed by searching for a local minimum point and assigning a label, and expanding the region based on the minimum point to which the label is assigned.

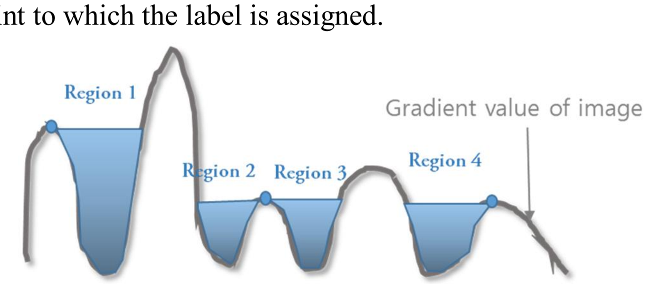

Figure 2. Watershed Algorithm

In the step of searching for minimum points and assigning labels, labels are assigned by searching minimum regions in the gradient image. The same label is assigned to the pixels connected to the labeled central minimum, and different labels are assigned to the distant minimum regions. In the step of merging the region based on the local minimum point to which the label is assigned, the label is merged based on the labeled points. When it encounters another label while expanding, it stops expanding, and the boundary points it meets become the boundary that separates the catchment basin. When the expansion of the area by catchment basin is completed, it is determined as one region.

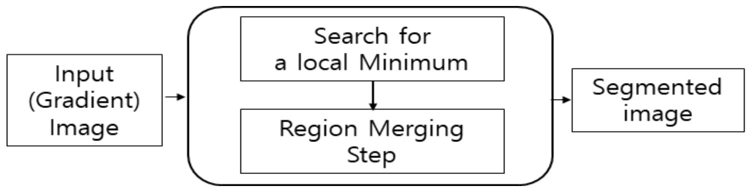

Figure 3. Flowchart of Watershed Algorithm

The watershed algorithm creates many regions, resulting in over-segmentation and inaccurate region boundaries. The over-segmentation is created by noise or by meaningless parts of an image. Therefore, although methods of merging these over-segmented regions have been proposed, many over-segmented and inaccurate regions are formed differently from the original image and require a lot of execution time.

3. Watershed algorithm for accurate boundary detection

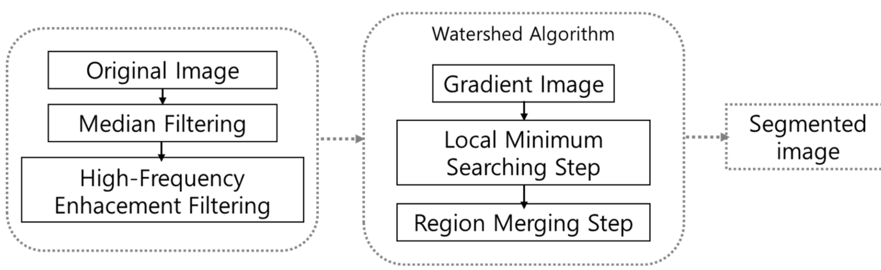

Figure 4. Flowchart of Proposed Method

Figure 4 is the flowchart of the proposed method. First, a high-frequency enhancement filter is used to emphasize the boundary before converting the original image into a gradient image to be used as an input for the watershed algorithm. A high-pass filter emphasizes high-frequency details, but loses low spatial-frequency components that are important in the image. However, the high-frequency enhancement filter solves this shortcoming. A loss of a component corresponding to a low spatial frequency can be compensated for to some extent by giving a certain amount of gain to a portion corresponding to cancellation of the low frequency region. Equation 1 is a method for generating a high frequency enhancement filter.

$$g(x,y) = Af(x,y) - f_L(x,y) = (A-1)f(x,y) + f(x,y) - f_L(x,y) = (A-1)f(x,y) + f_H(x,y) \quad (1)$$

$g(x,y)$ is the result of the loss-corrected high-frequency enhancement filter, f(x, y) is the original image, $f_L(x,y)$ is the low-frequency image, $f_H(x,y)$ is the high-frequency image and A is the gain value. Figure 5 is a high-frequency enhancement filter mask. It is possible to obtain an effect of adding a result image subjected to high-frequency filtering to an original image compensated as much as (A-1).

-1/9	-1/9	-1/9
-1/9	α/9	-1/9
-1/9	-1/9	-1/9

, $\alpha = 9A - 1$

Figure 5. High-Frequency Enhancement Filter Mask

In order to be used as an input image of the watershed algorithm, a high-frequency enhancement filtered image is converted into a gradient image. Next, a local minimum point is searched in the gradient image. When searching for local minimum points, a threshold is used. At this time, the threshold is important in determining the local minimum. If the value of the threshold is large, more minimum points are determined. It may be over-segmented or a local minimum may be assigned an infinite number of edge regions. Also, if the value of the threshold is small, a region other than an edge region may be treated as an edge region. Then, the portion to be allocated as the minimum point is not allocated, resulting in segmentation in which regions are not distinguished. Since determining the threshold globally does not reflect edge characteristics between adjacent pixels, a method of adaptively determining the threshold value by considering local characteristics is required when selecting a minimum point. Therefore, after edge-emphasizing high-frequency enhancement filter processing, a minimum point is retrieved by obtaining an adaptive threshold considering local edge characteristics. The threshold value T_1 is obtained as shown in Equation 2 using the average difference between the gradient value of the center and the gradient values of the surrounding 8 pixels.

$$T_1 = D \times \alpha \ , \quad D = \frac{1}{9}\sum_{m=-1}^{1}\sum_{n=-1}^{1}\left|\nabla x(i,\ j) - \nabla x(i+m,\ j+n)\right| \tag{2}$$

∇x(i, j) is the gradient value at the position (i, j), and α is a constant that reflects the difference in the gradient value and was determined as 2 by experiment

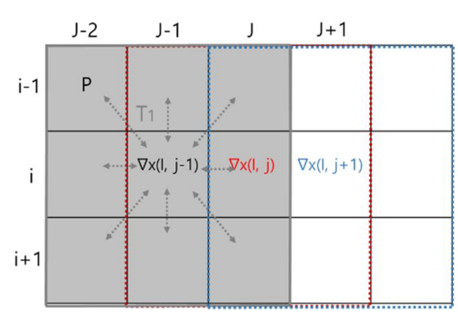

Figure 6. Local Minimum Searching using T_1

Figure 6 shows the local minimum point search process. ∇x(i, j-1) is the central gradient value. In order to find a local minimum point, a raster scan is performed in a 3×3 block by one pixel from the upper left corner of the image. Based on the central gradient value, the gradient values for the surrounding 8 pixels are searched and the difference between the central gradient value and the gradient value of the surrounding 8 pixels is calculated. If it is less than or equal to the threshold value T_1, the central gradient value is determined as the local minimum point. Otherwise, the central gradient value is not determined as the local minimum point. If the difference between the gradient value of P and is greater than T_1, ∇x(i, j-1) is not determined as the minimum point, and it moves to the position of the next ▽x(i, j). And, if the difference between ▽x(i, j) and the gradient value of the surrounding 8 pixels is less than or equal to T_1, ▽x(i, j) is determined as the minimum point. If the difference between the gradient values of adjacent pixels is large, it may be an edge area or a noisy area, so it is not assigned as a minimum point.

When the local minimum point is determined, region merging is performed based on the local minimum point. Region merging is performed based on the local minimum point stored in ascending order. Labels are assigned only to pixels that satisfy the threshold value T_2 of the center gradient value based on the local minimum point. That is, the center gradient values and the gradient values of the surrounding 8 pixels are compared with T_2, and the gradient values exceeding T_2 are not assigned a label. T_2 is a fixed threshold value and is used when merging a region. T_2 was determined experimentally. After the label allocation process for the central gradient value is completed, the merging is finished. Next, the same operation is repeated for other central gradient values. Equation 3 shows the comparison between the center gradient value and the surrounding gradient value when assigning labels.

$$L(i+k,\ j+l) = \begin{pmatrix} L(i,j),\ \ if\,|\nabla x(i,j)| < aT_2, \\ -1 \leqq k,l \leqq 1 \\ Unassigned, \quad\quad otherwise \end{pmatrix} \tag{3}$$

L(i+k, j+l) is a position where a label is assigned by comparing the difference between the central gradient and the surrounding gradient. If the difference between gradient values is less than T_2, a label is assigned, otherwise a label is not assigned. In the gradient image, a gradient value greater than the surrounding gradient values belongs to the boundary of the image. If a large gradient value belonging to the boundary area is assigned the same label as another small gradient value, a blocking effect of the image appears and the boundary of the object becomes inaccurate. Therefore, when merging a region, it is possible to find an accurate boundary by eliminating the blocking effect caused by assigning labels to positions with a large difference in gradient values.

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4. Experiments

In this paper, it was simulated using a 256×256 size image. The median filter is applied to the original image and the high frequency enhancement filter is processed.[8] The median filtering process is used to remove overall noise, and the high-frequency enhancement filtering process is to not remove significant parts even in the low-frequency range. Then, for use as an input to the watershed algorithm, the gradient image is obtained using the Sobel operator.[8]

Table 1. Number of label by each algorithm

Original Image	b	c	d	e	f
CoastGuard	11800	4168	3869	201	1558
hallMonitor	11090	5112	4267	261	2004
Table	11930	3084	2767	203	998

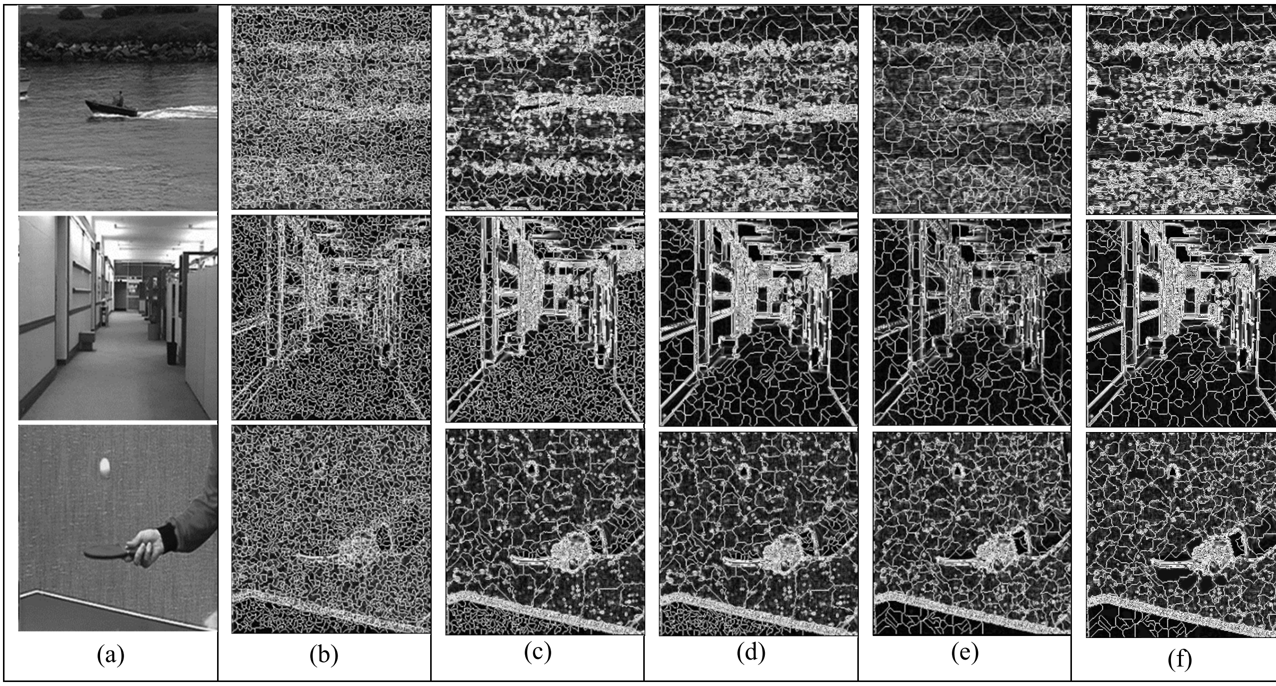

Figure 7. Segmented Image

Table 1 shows the number of segmented labels. (a) is the original image, (b) is Lantuejoul's method, (c) is the method using T_1=T_2=30[9], (d) is the method using adaptive T_1 and $T_2 = 30$[10], (e) is the method applying the adaptive threshold[11] and (f) is the result of applying the proposed method. The proposed method has a small number of labels except for method (e).

Figure 7 shows the results of segmentation of each image. As a result of applying the proposed method, it can be confirmed that over-segmentation is reduced as a whole in the image, and in particular, the boundary of the object is maintained. In the proposed method, although the number of divisions by method (e) is large, it can be seen that the boundary of the object is accurately divided.

5. Results

If image segmentation is performed by reducing only the number of labels, it may result in damage to the boundaries unique to the object. In this paper, we propose a method to improve this. The boundary is an important part of the image. A high-frequency filter process can be used to emphasize the boundaries. In this case, the image segmentation may be deteriorated by removing an important invisible low frequency region. Therefore, the proposed method applied a high-frequency enhancement filter, obtained a gradient image, and used it as the input image of the watershed. In the local minimum point search, the minimum point was searched by applying a threshold value suitable for the image in consideration of the local region. When merging regions, a fixed threshold was used.

The proposed method obtains a region segmentation result that matches the boundary of the original image by resolving the inaccurate boundary due to the blocking effect of the image while reducing the over-segmentation that appears as a result of the watershed algorithm. In addition, the proposed method reduced the number of segmented regions by about 58% while preserving the boundaries of the regions compared to when high frequency emphasis filters were not used.

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