A New Image Segmentation Method Based on Particle Swarm Optimization

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Abstract: *In this paper, a new segmentation method for images based on Particle Swarm Optimization (PSO) is proposed. The new method is produced through combining PSO algorithm with one of region-based image segmentation methods, which is named Seeded Region Growing (SRG).The algorithm of SRG method performs a segmentation of an image with respect to a set of points known as seeds. Two problems are related with SRG method, the first one is the choice of the similarity criteria of pixels in regions and the second problem is how to select the seeds. In the proposed method, PSO algorithm tries to solve the two problems of SRG method. The similarity criteria that will be solved is the best similarity difference between the pixel intensity and the region mean value. The proposed algorithm randomly initialise each particle in the swarm to contain K seed points (each seed point contains its location and similarity difference value) and then SRG algorithm is applied to each particle. PSO technique is then applied to refine the locations and similarity difference values of the K seed points. Finally, region merging is applied to remove small regions from the segmented image.*

Keywords: *Image segmentation, PSO, region-based segmentation, SRG.*

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1. Introduction

Image segmentation is one of the key stages in many image processing applications. It is a low-level image processing task that aims at partitioning an image into homogeneous regions [6]. The result of image segmentation is a set of regions that collectively cover the entire image, or a set of contours extracted from the image. All of the pixels in a region are similar with respect to some characteristic or computed property, such as colour, intensity, or texture [21]. The result of Image segmentation could be presented as input to higher-level processing tasks such as pattern recognition, computer vision and image compression.

Image segmentation methods have been divided into five categories: Pixel based segmentation [17], region based segmentation [12], edge based segmentation [4, 16], edge and region hybrid segmentation [19] and clustering based segmentation [2, 3, 8, 22].

Seeded Region Growing (SRG) presented in [12] is falling in region based category. The algorithm of SRG method performs a segmentation of an image with respect to a set of points known as seeds. Given a set of seeds, the algorithm of SRG then finds a tessellation of the image into homogeneous regions; each of which is grown around one of the seeds. The algorithm of SRG does not generate seeds automatically. To deal with this problem, some automatic seed selection methods have been presented in [7, 15]. In [7] three methods to automatically generate seeds are proposed. The first one partitions the image into a set of rectangular regions with fixed size and selects the centers of these rectangular regions as the seeds. The second method finds the edges of the image and obtains the initial seeds from the centroid of the colour edges. Finally, the third method extends the second method to deal with noise applying an image smoothing filter. In [15] a simple raster scan of the colour pixels is employed: from left to right and from top to bottom. At the beginning of the algorithm each pixel has its own label (one-pixel regions) and, then, a centroid or single linkage region growing algorithm is applied. Pre-processing (filtering) and post-processing (region merging) are applied to eliminate small regions. The homogeneity criteria, defined in RGB, YUV and IHS colour spaces, were tested. The Particle Swarm Optimization (PSO) is a kind of evolutionary computation techniques developed by Kennedy and Elberhart in 1995 based on the social behaviour metaphor [10]. PSO is a simple but powerful search technique; it has been applied successfully to a wide variety of search and optimization problems, including some image processing problems such as image segmentation, see [5, 11, 13].

This paper presents a new method for image segmentation based on PSO and SRG methods. The algorithm of PSO in the new method is applied to solve the two problems of the SRG method through refining the position and similarity difference value of each seed point. Finally, in the proposed method, region merging is applied to merge small regions in the segmented image.

The work in this paper is organised as follows. Section 2 gives an overview of the particle swarm optimization. Section 3 gives an overview of the original seeded region growing algorithm. Section 4 presents the proposed method. In section 5 the experimental results are presented and finally, the conclusions are stated in section 6.

2. Particles Swarm Optimization (PSO)

PSO are population-based optimization algorithms modelled after the simulation of social behaviour of birds in a flock [9, 10]. PSO is initialized with a group of random particles (solutions) and then searches for optima by updating generations. Each particle is flown through the search space, having its position adjusted based on its distance from its own personal best position and the distance from the best particle of the swarm. The performance of each particle, i.e., how close the particle is from the global optimum, is measured using a fitness function which depends on the optimization problem. Each particle i flies through the n-dimensional search space R^n and maintains the following information:

- x_i, the current position of the particle i(x-vector).
- p_i, the personal best position of the particle i(p-vector).
- v_i, the current velocity of the particle i(v-vector).

The personal best position associated with a particle i is the best position that the particle has visited so far. If f denotes the fitness function, then the personal best of particle i at a time step t is updated as:

$$p_i(t+1)=\begin{cases} p_i(t) & \text{if } f(x_i(t+1))\geq f(p_i(t)) \\ x_i(t+1) & \text{if } f(x_i(t+1))<f(p_i(t)) \end{cases} \quad (1)$$

If the position of the global best particle is denoted by gbest, then:

$$gbest \in \{p_0(t),\ p_1(t),\ \dots,\ p_m(t)\} = \min\{f(p_0(t)),\ f(p_1(t)),\ \dots,\ f(p_m(t))\} \quad (2)$$

The velocity updates are calculated as a linear combination of position and velocity vectors. Thus, the velocity of particle i is updated using equation 3 and the position of particle i is updated using equation 4:

$$v_i(t+1)=w\,v_i(t)+c_1\,r_1(p_i(t)-x_i(t)+c_2r_2\ gbest-x_i(t)) \quad (3)$$

$$x_i(t+1) = x_i(t)+ v_i(t+1) \quad (4)$$

In the formula, w is the inertia weight [17], c_1 and c_2 are the acceleration constants and r_1 and r_2 are random numbers in the rang [0,1]. V_i must be in a predefined range [V_{min}, V_{max}], where If $V_i > V_{max}$ then $V_i = V_{max}$, and if $V_i < V_{min}$ then $V_i = V_{min}$.

3. Seeded Region Growing

The seeded region growing approach to image segmentation is to segment an image into regions with respect to a set of n seed regions. Each seed region is a connected component comprising one or more points and is represented by a set A_i, where i = 1, 2 . . . n. Let T be the set of all unallocated pixels that border at least one of the A_i and $N(px)$ represents the set of immediate neighbours of the pixel $px\in$ T. A single step of the algorithm involves examining the neighbours of each $px\in T$ in turn. If $N(px)$ intersects a region A_j then a measure, $\partial(px)$, of the similarity difference between px and the intersected region is calculated. In the simplest case $\partial(px)$ is defined:

$$\partial(px)=|\,g(px) - mean_{y\,\in\,A_j}\{g(y)\}\,| \quad (5)$$

Where $g(px)$ is the intensity (gray value) of the pixel px. If $N(px)$ intersects more than one region then Aj is taken to be that region for which $\partial(px)$ is a minimum. In this way a ∂ value is determined for each $px\in T$. Finally, the pixel $z\in T$ that satisfies equation 6 is append to the region corresponding to $\partial(px)$.

$$\partial(z)= min_{px\,\in\,T}\{\partial(px)\} \quad (6)$$

The new state of the regions $\{A_i\}$ then constitute the input to the next iteration. This process continues until all of the image pixels have been assimilated.

4. A New Image Segmentation Method Based on PSO

The algorithm of SRG finds homogeneous regions around a set of given points called seeds. Two problems are related with this method, the first one is the choice of the similarity criteria of pixels in regions and the second problem and more difficult is to select the seeds, which affect directly the quality of segmentation. This work present a new segmentation method based on PSO and SRG methods, will be called PSO-SRG. The particle swarm optimization in PSO-SRG method tries to solve the two problems of SRG method. The algorithm of PSO-RG method, which will be introduced with details after PSO representation section, aims to find best locations for seed points and solve the similarity criteria of pixels in regions. The similarity criteria that will be found by PSO-SRG algorithm is the best difference between the gray value of examining neighbour pixel and the mean of intersected region see equation 5.

4.1. PSO Representation

One of the key issues in designing a successful PSO algorithm is the representation step, i.e., finding a suitable mapping between a problem and PSO particles. Figure 1 shows the PSO representation (structure) that is used in PSO-SRG method. The structure of PSO in PSO-SRG method contains three levels. The first one includes the fields of swarm, the second level includes the fields of particle and the fields of seed point are included in the third level.

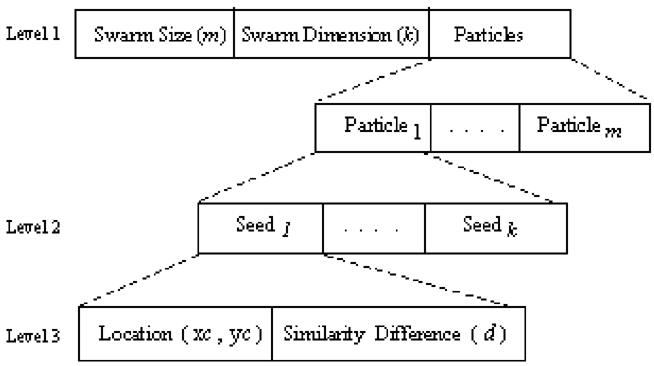


Figure 1. PSO representation of RB-SRG method.

The PSO in PSO-SRG method, as we can see from Figure 1, have the following information:

- *Swarm Size (m):* Represents the number of particles in the swarm.
- *Swarm Dimension (k):* Represents the number of seed points in each particle.
- *Location (xc, yc):* Represents the x- coordinate and y-coordinate of seed point, which will be selected randomly in first iteration. In this paper, *xc* denotes x-coordinate and *yc* denotes y-coordinate.
- *Similarity Difference (d):* Represents the similarity deference value of seed point. The similarity difference value is used to govern the growing of regions in SRG Algorithm and will be generated randomly in first iteration.

In PSO of RB-PSO method, a single particle represents k Seed points. That is, each vector x_i is constructed as $x_i=(S_{i,1}, \dots, S_{i,j}, \dots, S_{i,k})$ where $S_{i,j}$ refers to the j^{th} seed point of the i^{th} particle. Each seed point $S_{i,j}$ is constructed as $S_{i,j}=(xc_{i,j}, yc_{i,j}, d_{i,j})$, where $xc_{i,j}$, $yc_{i,j}$ and $d_{i,j}$ refers to the *x*-coordinate, *y*-coordinate and similarity difference value of j^{th} seed point in i^{th} particle respectively. Therefore, in PSO-SRG method after applying SRG algorithm to each particle, a swarm represents a number of segmented images.

4.2. PSO-SRG Algorithm

As we mentioned above our work aims to produce a new segmentation method through combining particle swarm optimization with seeded region growing segmentation method, named PSO-SRG. In PSO-SRG method each particle is initialized randomly to contain K seed points (each one contains x-coordinate, y-coordinate and similarity difference value). The seeded region growing algorithm is then applied to each particle. After that, the fitness function for each particle is calculated and the global best solution (gbest) is computed. The updates of PSO velocities and vectors are then done. This procedure is repeated until a number of iterations or a stopping criterion is satisfied. For the best solution, unallocated (unlabeled) pixels, if any, are segmented and region merging is applied to remove small regions. The PSO-SRG algorithm is summarized in Figure 2.

1. *Do 3×3 Low pass filter (Pre-processing).*
2. *Initialize randomly each particle to contains k seed points.*
3. *Repeat the following steps Until number of iteration or stopping condition is satisfied.*
   a. *For each particle i :*
      1. *Segment the image using the seed points of particle i,(using seeded region growing method).*
      2. *Compute the fitness of particle i, f (i).*
   b. *Find the global best solution (gbest).*
   c. *For each particle i, Update the seed points.*
4. *Segment unlabeled pixels of the best solution, if any.*
5. *Merge small regions of the best solution.*

Figure 2. The algorithm of new method PSO-SRG.

To eliminate small region two stages are added to the algorithm, pre-processing stage and post-processing stage. In the pre-processing stage 3×3 low pass filter is applied and in the post-processing stage small regions, which are less than a predefined number (e.g., 20 pixels), are merged with their neighbor regions. The algorithm after the low pass filter initializes the vectors of each particle randomly. The *x*-coordinates of seed points in each particle are initialized in the range [0, $Image_{width}$], y-coordinates are initialized in the range [0, $Image_{high}$] and similarity difference values are initialized in a predefined rang [d_{min}, d_{max}]. Every particle has its seed points, for each particle seeded region growing algorithm is applied separately. The SRG algorithm is summarized in Figure 3.

1. *Start with the first seed point.*
2. *Choose neighboring pixels based on a connectivity and Merge pixels that satisfy the homogeneity condition.*
3. *If the region doesn't grow anymore Select another seed point and Repeat the process.*

Figure 3. The algorithm of SRG method.

In SRG algorithm, for connectivity 4-connectivity will be used and for homogeneity similarity difference will be used. The neighbor pixel, *px*, is append to the region $A_{i,j}$ if equation 7 is satisfied.

$$| g(px) - mean_{a \in A_j} \{ g(a) \} | < d_{i,j} \tag{7}$$

Where $A_{i,j}$ is the region of the j^{th} seed point in the i^{th} paritcle and di,j is the similarity difference value of the j^{th} seed point in the i^{th} particle. The global best solution (gbest) is the particle that has the best fitness value. The fitness of the i^{th} particle is evaluated according to a selected fitness function, below three fitness functions are suggested.

In PSO-SRG method the locations of k seed points are initially generated randomly, so in some cases two problems will happened, In first one many of unallocated (unlabeled) pixels are found and In second problem, some of seed points do not grow (du to the occurrence of more than one seed point in the same region). The second problem makes number of segmented region smaller than the number of seed points, k. In first fitness function, equation 7, PSO tries to minimize the number of unallocated pixels and maximize the number of segmented regions as follows:

$$f(i)=j_1(Np/Na_i)+j_2(k/Nr_i) \tag{8}$$

Where:

- Na_i: Denotes the number of allocated pixels in the i^{th} particle.
- Np: Denotes the number of image pixels.
- J_1 & j_2: Constants are used to weight the function.
- Nr_i: Denotes the number of segmented regions in the i^{th} particle.
- k: Denotes the number of seed points.

In some cases the seed points and their similarity difference values produce bad regions, greater or smaller than the expected regions, so equation 8 is developed in equation 9. In second fitness function equation 9, PSO Algorithm tries to minimize the number of unallocated pixels and maximize the number of segmented regions as follows:

$$f(i)=j_1(Np/Na_i) + j_2(k/NS_i) \tag{9}$$

Where:

$$Nsi = \sum_{j=1}^{k} Z(Nc_{i,j}) \tag{10}$$

- $Nc_{i,j}$: Denotes the number of pixels in j^{th} region of particle i.
- Z: Is computed as follows:

$$Z(s)=\begin{cases} 1 & \text{If} \quad N1 < s < N2 \\ 0 & \text{Otherwise.} \end{cases} \tag{11}$$

- N_1&N_2: Constants govern the number of pixels in each region.

The Mean Square Error (MSE) can be also used to refine the result of the fitness function (The MSE will refine the result of the fitness function through increasing the number of the homogeneous regions). In the third fitness function, equation 12, PSO Algorithm tries to minimize the number of unallocated pixels, maximize the number of segmented regions and minimize the mean squire error between intensities of pixels as follows:

$$f(i)= j_1(Np/Na_i)+j_2(Ns_i/k)+j_3(\sum_{j=1} MSE(R_{i,j})/Na_i) \tag{12}$$

Where:

- $R_{i,j}$: Denotes the j^{th} region of particle i.

$$MSE(R_{i,j})=\sum_{\forall px \in R_{i,j}} (g(px)-(R_{i,j})_{mean})^2 \tag{13}$$

- $g(px)$: Denotes the gray value of the pixel px.
- $(R_{i,j})_{mean}$: Denotes the mean of region $R_{i,j}$.

The x-coordinate and y-coordinate of each seed point are updated using equations 3 and 4 in 2-dimention space (i,j), where i represents i^{th} particle and j represents j^{th} seed point. Also, similarity difference values are updated using equations 3 and 4 in 2-dimention space (i,j), where i represents i^{th} particle and j represents j^{th} seed point.

Step 3 of PSO-SRG algorithm shown in Figure 2 is repeated until a stopping criterion or the number of iteration is satisfied (in our experiments we used number of iterations). The segmented image of global best solution after final iteration is chosen as the optimal result. For the optimal segmentation two steps must be done: segmenting unlabeled pixels and merging small regions. In segmenting unlabeled pixels step, the target image is scanned from left to right and from top to bottom to check and segment the unlabeled pixels, if any. The segmenting unallocated pixels step is summarized in Figure 4.

For each Pixel , px, in the target image
If Pixel, px, is unlabeled Then
1. Do Seeded Region Growing algorithm using the seed point px with similarity difference $d=(d_{min} + d_{max})/2$.
2. Add new region to region list.
End If
End For

Figure 4. Segmenting unlabeled pixels step.

In the merging small regions step, the final list of regions is scanned to merge small regions, which have pixels less than a predefined number (e.g., 20 pixels), with their neighbouring regions that satisfy a similarity condition. The similarity condition here is the smallest difference between means. In PSO-SRG method, the number of final segmented regions is determined after merging small regions step.

5. Experimental Results

The proposed algorithm has been tested successfully on different natural images. In this section we will present the result obtained from applying PSO-SRG method on a 256×256 pixels image, named Cameraman image, shown in Figure 6-a. The PSO parameters of PSO-SRG algorithm were initially set as in Figure 5 and the fitness function that was used is the function declared in equation 12, N2 is equalled to zero to compute the regions that greater than N1 only (circled in figure). The PSO algorithm in PSO-SRG method used the information settings shown in Figure 5 to get the best segmentation for cameraman image, Figure 6-b shows the best segmentation for cameraman image obtained after final iteration of PSO algorithm and Figure 6-c shows the best locations of the assigned seed points.

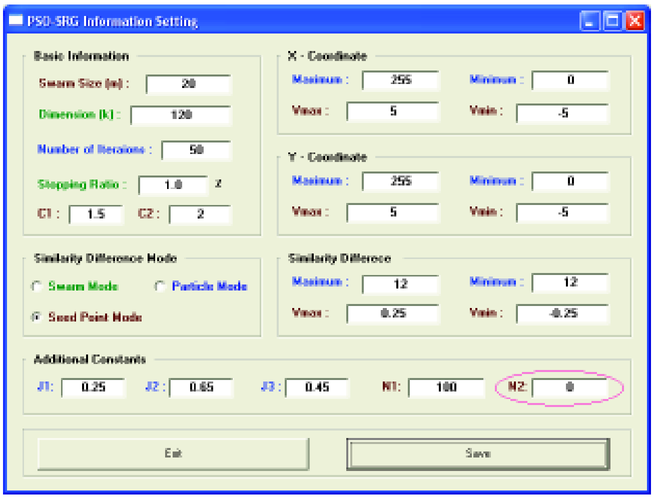


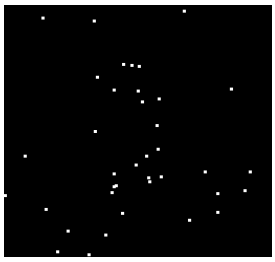
Figure 5. PSO information settings of PSO-SRG method.

Finally, the algorithm of PSO-SRG allocated the unlabeled pixels of the best solution, Figure 6-d shows the best solution after allocating unlabeled pixels. To eliminate small regions, the PSO-SRG algorithm merges small regions, that are less than a predefined number, with their neighbouring regions (In this experiment PSO-SRG algorithm merges small regions that have pixels less than 20 pixels). Figure 6-e shows the best solution after merging small region and Figure 6-f shows the final seed points. As we mentioned above, the number of final regions (relatively the number of final seed points) is determined after merging step, clearly we can see from Figure 6-f that the number of seed points after merging step is greater than the number of seed points shown in Figure 6-c.

There is not a generally accepted methodology (in the field of computer vision) which elucidates on how to evaluate segmentation algorithms [14, 20]. So, the most common method for segmentation quality evaluation is a visual inspection made by domain experts.

a) 256×256 Cameraman image.

b) Best segmentation obtained by PSO algorithm.



c) Positions of best seed points.

d) Best solution after allocating unlabeled pixels.

e) Best solution after merging step.

f) Final seed points.

Figure 6. Applying PSO-SRG method.

Comparing different segmentation algorithms with each other is difficult mainly because they differ in the properties they try to satisfy [14]. For the comparison of the proposed method, the best solution of above experiment is compared with the result that produced by implementing the region-based image segmentation method presented in [15]. The region-based method is implemented in gray level colour space, similarity difference (d=12) and merging regions that less than 20 pixels. Figure 7-a shows the result produced by PSO-SRG method and Figure 7-b shows the result produced by region-based method. It can be observed that the proposed algorithm can find more homogenous regions than region-based method.

a) With PSO-SRG.

b) With Region-based.

Figure 7. Cameraman image segmentation.

6. Conclusions

In this work particle swarm optimization has been merged with seeded region growing segmentation method to produce a new image segmentation method, called PSO-SRG. PSO algorithm in PSO-SRG method tries to find the best locations for the seed points, and to find the best similarity difference between regions and their neighbours pixels. Three objective functions have been suggested to increase the quality of the PSO-SRG method. The algorithm of PSO-SRG is flexible where many objective functions can be used, for this reason PSO-SRG method can be used in the oriented segmentation such as medical image segmentation and segmentation based image compression.

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