A New Satellite Image Segmentation Enhancement Technique for Weak Image Boundaries Based on Active Contours and Level Set Method

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ABSTRACT: Level Set Method (LSM) and Snakes Method (SM) are two different procedures used in image processing to locate objects location and boundaries. Both of these methods have their own advantages and limitations. In this research, a new algorithm for image processing of the weak gradient features was developed to improve the overall image boundary detection system. This algorithm was based on the active contour model in conjunction with level set method to enhance the images detection approach. The algorithm presented a new technique to incorporate the advantages of both LSM and SM. First, different bands of satellite image from a region were extracted from the satellite scene and then by linear combination of these images, the obtained image was resulted enhanced image. After combination the bands of satellite image, the initial segmentation by LSM was transformed and used as an input for the SM and began its evolvement to the interested object boundary. The results showed that the algorithm can deal with low contrast images and features on them, demonstrates the segmentation accuracy under weak image boundaries, which responsible for lacking accuracy in image detecting techniques. Thus, better segmentation and boundary detecting for the satellite images were achieved and ability of the system to improve low contrast images and low gradient features increased and as a result, they can deal with over and under segmentation.

Keywords: Active contours, Boundaries, Connected components, Feature extraction, Level-Set Method, Remote sensing, Segmentation.

Abbreviations: LSM: Level Set Method, SM: Snakes Method

Introduction

Image Feature Extraction is useful technique for image segmentation in Digital Image Processing. Using satellite and aerial image analysis in order to change detection in local level or even global level is one of the countless advantages of usage of satellite images. Because of too much information in satellite scenes, automatic feature extraction is not possible and segmentation is done manually. There are different methods for Image Segmentation and in these methods optimized results are visually determined by the user. User should enter the important information for Segmentation Algorithm. This information includes number of classes or initial seeds of segment(s) of input data (Gonzalez and Woods, 2002).

Geometric deformable models, such as Level Set Method (LSM) and active contours (also known as Snake Model (SM)) are used extensively in image processing applications including region-based and edge-based extraction of features, respectively. Some of the applications for these methods are land features detection in satellite imagery and detection of the object boundaries in medical image analysis. Both of these methods use energy minimization to find image features regions or edges, but have their own advantages and limitations. The binarized image by LSM is firstly transformed into the input of the Active Contour method and begins its approach to the interested object boundary (Ashraf et al., 2011). Xu et al. (2001) presented a mathematical relationship between the active contour and surface models, such as spatially varying coefficients and external forces. Keaton and Brokish (2002) used LSM for extraction of roads from multispectral imagery. This method needed a precisely user defined initial single seed point
to grow and extract the road network. Extraction of the road centerline and preserving its connectivity was the objective in this method. Precision of this method was completely based on correct definition of initial seed point. Also, if the road network was not continuous, user would have to define more than one initial point. A comparison between this method and proposed method in current research has been done by the end of the research. Hinz(2008) has automatically extracted objects for change detection and GIS update depends on user clicks. In this article, automatic and semi-automatic methods were compared to each other and finally, semi-automatic methods were defined as more precise methods; however, automatic methods were defined as non-user interactive methods. There were four parameters that introduced for feature extraction by the article. By knowing these parameters, user could find the best method to solve the problem: level of automation needed, characteristics of available sensors and images, effectiveness and processing time, and verification/editing and quality of results.

Ekerand Seker(2008) presented a semi-automatic extraction of features. This method needed to define an initial seed point defined in the road domain by user to grow in image spectral bands for extracting the road network, but definition of a correct value of tolerance was needed. In this method, unrelated features in the image domain affected the result of extraction of interested features. Finally, LSM created a binary segmented image. Raster to vector software was used to export the road from binarized image. In another study, an automatic road extraction based on statistical region merging (SRM) was presented. The result of this method was the road centerline. At the first step, image segmentation was done by thresholding. Next, SRM was used to merge the same regions. At the next step, discrete curve evolution was used to skeletonize the road network to extract the road centerline (Anil and Natarajan, 2010). The road cast by shadows cannot be extracted in this method. Rajeswari et al. (2011) extracted roads based on LSM and mean shift methods. The main idea in this research was segmenting image into two classes - roads and non-roads classes - by remaining the road class from an unsupervised classification. Next, it merged similar classes of classification result by applying nearest neighborhood method. Finally, LSM extracted the roads from result image.

In this research, a new algorithm was developed for image processing of weak gradient features to eliminate the defects of both LSM and SM and also no needs to define initial seed in the interested region or performing any threshold.

Materials and Methods

In this study, active contours method was used in conjunction with LSM, because of these methods have their own advantages and limitations. The advantage of one method eliminates the limitation of the other method. Sometimes, continuous features in the nature such as rivers or roads are extracted as discontinuous features. This case may happen as a result of sensor nature or its condition at the moment of take photo. This will affect the grey-level of pixels placed on the continuous feature. Therefore, the grey-level of neighbor pixels on the feature will be different at the moment. This disadvantage will be reduced by increasing spatial resolution in high resolution satellite imageries, but will still remain. Therefore, if the purpose is extraction of continuous linear features from satellite scenes, LSM cannot make connections and extract continuous features. The mentioned disadvantage causes discontinuous extraction of continuous features, and can be solved by using this method and active contour method simultaneously.

We can summarize our proposed method to the sentences below:

- Utilizing LSM on each spectral band of the satellite multi-spectral scene to create related binarized images separately.
- Combination of resultant binarized images in order to extract maximum number of features from input image and creating final binarized image.
- Utilizing connected component method to reduce the number of non-linear features in the final binarized image (if the purpose is linear features extraction).
- User clicks to create initial contours for fitting on the linear features and extract features boundaries.

In this research, proposed method also needed user clicks in the SM stage, but final objects were extracted by fewer clicks because of low amount of unrelated features remains in the resultant image. This method used these algorithms on the image, respectively. The feature image was obtained by LSM and then, was optimized by connected component method, considered as the input of Snake Method (SM). After that, boundaries of determined regions were extracted. Then, description of these two methods and optimization of their results by using connected component method is presented.

**Snake method (SM)**
SM is a parametric curve defined in the image domain by equation (1) and is one of image segmentation algorithms (Kass et al., 1987).

\[
\nu(s) = (x(s), y(s)), \quad s \in [0,1] \tag{1}
\]

Where: \(s\) is curve length and \(\nu(s)\) is a function of curve length. Snakes are initial contours defined in the image domain that can move under the influence of the vector field created by local grey-level gradient of the desired feature in image, and can lead the curve to the boundaries of image. In this method, final extracted boundary is continuous, because curve deformation is done with initial continuous gradient of the desired feature in image, and can lead the curve to the boundaries of image. In this method must be binarized and region of interests in pre-processing must be well segmented to prevent of creating energy valleys in the neighborhood of desirable feature boundaries. If there is a high amount of aggregation of irrelevant feature grey-level in the image, the resulted external energy will be significant and causes the deviation of points of initial contour. Therefore, the results will not proper. Because of high details in satellite images, a pre-processing on the input image is necessary to eliminate significant and causes the deviation of points of initial contour. Therefore, the results will not proper.

Equation 2 shows the energy function in SM (Kass et al., 1987).

\[
E_{Snake} = \frac{1}{0} E_{Internal}(\nu(s))ds + \frac{1}{0} E_{Image}(\nu(s))ds + \frac{1}{0} E_{Condition}(\nu(s))ds \tag{2}
\]

Where: \(E_{Internal}\) is Internal energy, \(E\) is Image energy and \(E_{Condition}\) is Condition energy. \(E_{Condition}\) is a result of further constraints defined by user and gives rise to the external constraint forces in the image. This constraint is defined to eliminate approach to specific features (peak of energy), or made approach to other specific features (valley of energy). In other words, if the contour approaches to the features boundaries, it will choose the easiest way to move. For example, the curve do not have tendency to climb a peak when it can fall in the valleys. \(E_{Condition}\) can provide by image participant information such as DEM (Digital Elevation Model) or the energy created by user. \(E_{Internal}\) represents internal curve deformation energy and can be written as equation (3)(Kass et al., 1987).

\[
E_{Internal} = \frac{1}{2} \int (\alpha(s)|\nu'(s)|^2 + \beta(s)|\nu''(s)|^2)ds \tag{3}
\]

Where: \(\alpha\) and \(\beta\) are elasticity and stiffness of the snake, respectively. \(E\), also in more cases known as \(E_{Ex}\), represents the force developed by the change in gradient of grey-level in the image and can be derived from equation (4) (Kass et al., 1987).

\[
E_{Image} = -\int |\nabla I(x,y)|^2 \tag{4}
\]

Where: \(I\) is intensity of the image grey-level. The purpose of SM is to minimize energy function, so the goodness of fit test is usually derived from energy integration on contour points. If energy integration satisfies the local energy minimization constraint on any point, that point of the contour will stand at its place. This procedure will do for all other points and defines the time of finishing the fitting.

The limitation of feature extraction from satellite images in using SM is that the input image for this method must be binarized and region of interests in pre-processing must be well segmented to prevent of creating energy valleys in the neighborhood of desirable feature boundaries. If there is a high amount of aggregation of irrelevant feature grey-level in the image, the resulted external energy will be significant and causes the deviation of points of initial contour. Therefore, the results will not proper. Because of high details in satellite images, a pre-processing on the input image is necessary to eliminate the irrelevant features in this algorithm. Before SM processing on the image, LSM was used for image segmentation. The principal of LSM is changes in grey-level gradient on boundaries, and there is no need to Threshold definition.

**Level set method (LSM)**
Because of using Local Grey-level gradients, there is no need to initial parameters definition in LSM, and image segmentation is done automatically. One of the limitations in this method is over segmentation, because of this method is defined on the concepts of Local Gradients. Over segmentation includes many segments with the shape of points and small lines everywhere in the resulted image in LSM. For example, we can identify a region as a segment visually, but this method divides it to the smaller segments. Therefore, region merging technique is used beside the LSM for Segmentation to identify the boundaries of segments properly. However, using of region merging technique for filling the gaps smaller than a specific size seems to be good, but it can make wrong connections between unrelated branches of the linear feature. Therefore, if we need feature extraction with a precision about pixel size or even better, this method will be useless. The defects of LSM are surmounted by using SM simultaneously.

Nevertheless, SM cannot deal alone with over segmentation. That is because of large amount of noisy point features extracted from this stage. These noisy points can create a powerful energy field to attract the curve from active contour method and prevent it in approach to features boundaries. Since the purpose of this article is extraction of linear features, a minimum length was determined to extract features in LSM.

At the first step in LSM, defined initial curve splits the image into two segments (inside of the curve segment and outside of the curve segment). This curve creates an energy field in the image and causes initial curve gathered to its center of gravity. The grey-level of features that positioned crossover with the points on this curve, shifted to create a hole inside the regions of features. Since this happened in spatial domain, this property will be achieved by convolution of Heaviside Function (equation (5)) on image points with deformation in the initial curve simultaneously.

\[
H_\alpha(\phi) = \begin{cases} 1 & , \phi > \alpha \\ 0 & , \phi < -\alpha \\ \frac{1}{2}(1 + \frac{\phi}{\alpha} + \frac{1}{\pi} \sin(\frac{\pi \phi}{\alpha})) , |\phi| < \alpha \end{cases} \tag{5}
\]

Where: \(H\) is Heaviside function, \(\phi\) is interval around the boundary and \(\alpha\) is the initial curve in spatial domain. Formulation of LSM to reach the zero-level set is defined as equation (6).

\[
C = \{(x, y) | \phi(x, y) = 0\} \tag{6}
\]

Thus, the Chan-Vese energy function can be calculated by equation (7) (Chan and Vese, 2001).

\[
C(\phi, a_1, a_2) = C_1(\phi, a_1, a_2) + C_2(\phi, a_1, a_2) = \int \left[ H_\alpha(\phi)(I(x, y) - a_1)^2 \right] dxdy_{\text{inside}(\phi)} + \int \left[ (1 - H_\alpha(\phi))(I(x, y) - a_2)^2 \right] dxdy_{\text{outside}(\phi)} \tag{7}
\]

Where: Constants \(a_1\) and \(a_2\) are mean intensities of the interior and exterior pixels of the segmented objects. In order to find the minimum value of \(C(\emptyset, a)\), we have to find its derivatives and set them to zero. By taking Euler-Lagrange equation and updating \(C_1, C_2\) and recursively, they can be written as equation (8).

\[
\begin{align*}
C_1(\phi) = & \frac{\int H_\alpha(\phi)I(x, y) dxdy_{\text{inside}(\phi)}}{\int H_\alpha(\phi) dxdy_{\text{inside}(\phi)}} \\
C_2(\phi) = & \frac{\int (1 - H_\alpha(\phi))I(x, y) dxdy_{\text{outside}(\phi)}}{\int (1 - H_\alpha(\phi)) dxdy_{\text{outside}(\phi)}}
\end{align*} \tag{8}
\]
\( C_1 \) and \( C_2 \) minimize the Chan-Vese energy functional from equation (7) by utilizing equation (9) (Chan and Vese, 2001).

\[
\frac{\partial \phi}{\partial t} = \delta_{\phi} \left( (\nabla \cdot \nabla \phi) - (I(x, y) - C_1(\phi))^2 + (I(x, y) - C_2(\phi))^2 \right)
\]  

(9)

Where: \( \phi \) is the area inside the input image. The input image was divided into two regions - inside and outside of the feature - by using equation (9) and finally the binary image was resulted.

**Connected components method**

As was described, usage LSM on binarized image will faced to over segmentation. Therefore, connected components method and remaining of features greater than a minimum length was described in the proposed method to eliminate the effect of small components for attracting active contour from its approach to the features boundaries in the image. The purpose of this method is to define a constraint based on features kind with equal property for equal features. For example, if the purpose is to extract buildings from a binarized image -desired feature and non-desired features, the length to width ratio of extracted connected components will not exceeds a specific value. Therefore, the specific value should be defined once for all the same kind of that image. If the problem desire is river extraction, it is sufficient to consider the minimum length or the ratio of minimum length to width.

**Results and discussion**

There were many features in satellite images that segmented as a point and increased final segmented image noise. Therefore, optimized image was obtained using connected component and minimum length definition. Roughness and discontinuity on the features boundaries was eliminated by SM. The flow chart in figure 1 describes the method performance.

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Fig.1: Flow chart of extracting and smoothing feature boundaries using active contour model in combination with LSM result, enhanced by connected components method

Quick-Bird multi spectral scenes method was used for feature extraction. These scenes contained four spectral bands (Red, Green, Blue and Near Infrared), and a panchromatic band.
Spatial resolution of this sensor for spectral bands was equal to 2.44 meters, and was equal to 61 centimeters for panchromatic band (figure 3).

As was discussed before, purpose was features boundary extraction using active contour model. Therefore, the binarized features image was needed. We used LSM to create this binary image.

In panchromatic image, over segmentation was occurred as a result of its high spatial resolution (figure 4(a)). In order to prevent this case and to improve features boundary quality, we used all four spectral bands in the sensor scenes. In the first step, LSM was done automatically on every four Near IR and visible bands separately, and resultant was four binarized images. Desired feature could completely extract from combination of four bands. If image segmentation was done on one spectral band, under segmentation would be happen. Therefore, the extraction possibility of desired feature decreased because of increasing in discontinuities on the feature. Thus, active contour model failed to extract its real shape. An image with maximum amount of related features and no over segmentation could be achieved by combination of four spectral bands from equation 10.

An image with less details and more relation to the related feature could be obtained by the grey-level averaging of four binarized bands (figure 4(b)).
Fig. 4: Features extracted by LSM from, (a) Panchromatic image, (b) Multispectral image. We can see over segmentation in panchromatic image.

\[
\text{Segmented image} = \frac{\text{seg}1 + \text{seg}2 + \text{seg}3 + \text{seg}4}{4} \quad (10)
\]

Where: seg1 to seg4 are segmented images by developing LSM on blue, green, red and near IR bands, respectively. Final segmented image was obtained from averaging of these four binary images. But still there were lots of details in it. In the next part of proposed method in this article, connected components method was used to identify related features. In this method, a minimum length was defined for each connected component, so features smaller than minimum length were eliminated from segmented image. This limited number of features in the segmented image. As the results, linear feature extraction is presented. The important property of these features was the big ratio of their length to width. Therefore, in connected component stage, a minimum of 20 pixels length was defined to take the feature into account as a linear feature such as river in an image with 1024x1024 pixels dimensions. In this case, if there were still discontinuities on linear feature that could not be eliminated from previous enhancements, they would be resolved by active contours (figure 5).

Fig. 5: Decreased image features by utilizing connected components (a) on the Multispectral image, (b) on the panchromatic image.

At last, the final binarized image with less number of unrelated features was reached. But there were still a few numbers of nonlinear features from the same kind of linear feature such as lakes. In this step, active contour model extracted rivers boundaries (figure 6).
In order to better representation of the performance of proposed method in this research and other methods, a quantitative analysis is performed on 15 test images with 1024x1024 pixels dimensions from Quick-Bird sensor imagery. A comparison on accuracy, precision and number of discontinuities against Mean Shift Method (MSM) is presented in table 1. There is also a comparison between proposed method which is made of three steps (LSM, Connected components method and SM), with LSM and also with LSM+SM. All these measurements are based on number of pixels located on features boundary.

In table 1, accuracy criterion for every four methods is computed from ratio of the number of correctly segmented pixels as feature boundary to the sum of segmented pixels in the image domain by counting. Therefore, extraction of unrelated pixels as related pixels reduced the accuracy. The accuracy of LSM was less than proposed method, because of more unrelated pixels in the result. In using SM in conjunction with LSM (LSM+SM), the curve of active contour was attracted to the energy field of remaining unrelated features near to the boundaries. But as a reason of defining initial active contour with a few number of user clicks, unrelated features did not extract from segmented image of LSM, and the accuracy increased. Another reason for increasing the accuracy of this method was continuous definition of active contour model. This definition eliminated small discontinuities between features and also increased mean gap length and reduced number of them in image domain. This is exactly what we desire.

In addition to mentioned advantages, proposed method can solve the problem of fitting active contour to unrelated features by elimination of connected components smaller than 20 pixels. MSM precision was affected by the need to introduce a proper threshold and also similarity of feature to the background in some regions.

Precision was computed from ratio of the number of pixels completely located on the boundaries by counting pixels to the number of pixels expected from boundaries. Counting of these pixels was quite manually. User highlighted boundary pixels by clicking them and export of result showed the number of pixels located on the boundaries. Finally, specified pixels counted by MathWorks MATLAB R2011b software. The precision of the proposed method was quite depends on LSM precision in feature extraction. Therefore, active contour model eliminated discontinuities and precision of proposed method increased. But in using LSM+SM, unrelated features around feature boundary caused to deviation of curve. Therefore, precision of proposed method was a bit higher. The precision of MSM was affected by boundary change from median filter used to filter parts of road not related to the main road network. Precision in this method also depended on global threshold of grey-level defined by user.

Great value of mean gap length stands for better performance against small discontinuities. Therefore, it can better eliminate them, and remaining discontinuities in the image have a greater length.

For 15 test images (1024x1024 pixels dimensions), using modified LSM took average 9.83 seconds for segmentation (compared to about 270 seconds for usual LSM), and about 3 minutes to select initial points of active contour with perform its approach to the related object boundary, and about 2 minutes to remove connected components smaller than 20 pixels length. The computer used for these calculations was a laptop with Intel(R) Core(TM) 2 Dual CPU T9600 with 2.8 GHz. Overall proposed method was better than LSM, LSM+SM or even MSM.
Table 1: Performance evaluation of LSM, LSM+SM, MSM and proposed method

<table>
<thead>
<tr>
<th>Quality Measure</th>
<th>LSM</th>
<th>LSM+SM</th>
<th>MSM</th>
<th>LSM + Connected components + SM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy (%)</td>
<td>91.71</td>
<td>97.11</td>
<td>97.48</td>
<td>98.30</td>
</tr>
<tr>
<td>Precision (%)</td>
<td>97.00</td>
<td>97.29</td>
<td>98.40</td>
<td>99.02</td>
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<tr>
<td>Number of gaps per kilometer</td>
<td>2.15</td>
<td>0.90</td>
<td>1.82</td>
<td>0.90</td>
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<tr>
<td>Mean gap length (m)</td>
<td>8.13</td>
<td>14.54</td>
<td>12.66</td>
<td>14.54</td>
</tr>
</tbody>
</table>

Conclusion

In this article, linkage and extraction of features boundary using active contour model based on binary image from LSM in conjunction with connected components was presented. Combination of the results of performing LSM on every different spectral bands of the multispectral satellite scene created a binary image with less unrelated features, but we had still faced to over segmentation. Therefore, in order to create a binary image with less unrelated features, connected component method was used to eliminate the linear connected components with a minimum length less than 20 pixels. Final binary image from this step had less number of unrelated features, but there were still few numbers of unrelated features that forced user to perform a few numbers of clicks of initial active contour curve close to the features boundaries. Results showed the ability of the proposed method to overcome extraction of low-contrast features in the image.

In other hand, disability of using panchromatic band can be mentioned as a disadvantage for this method. In despite of high amount of spatial information, there was no spectral information in panchromatic band. Altogether, we have achieved better segmentation and boundary detecting for the linear features in satellite images. The ability of the system to improve the low-contrast features can deal with over and under segmentation.

References


