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Automated Road Extraction From High Resolution Satellite Images

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Abstract

The importance of road extraction from satellite images arises from the fact that it greatly enhances the efficiency of map generation and thus can be a big help in car navigations systems or any emergency (rescue) system that needs instant maps. Therefore, increasing research is being dedicated and focused on the development of efficient methods to extract topographical meaningful features (like roads) from digital remote sensed images. The work deals with extraction of roads from satellite images. This is a challenging domain compared to extraction from aerial images as satellite images are noisy and of lower resolution. In this method, a Vectorization Approach for the automatic method of road extraction is being used where the image is segmented to identify the road network regions followed by a decision making and continuity procedure to correctly detect the roads and the Vectorization step to identify the line segments or curved segments which represents the road. This method may be employed for obtaining information for feeding large-scale Geographic Information System. In the automatic method of road extraction the extracted roads are converted into road vectors in order to use these vector road maps in GIS. A semi-automated scheme is used for scenarios where fully automated system fails. A combination of both methods can be devised for a full fledged real business scenario

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1. Introduction

Satellite imagery consists of photographs of Earth or other planets made by means of artificial satellites. Satellite images have many applications in agriculture, geology, forestry, biodiversity conservation, regional planning, education, intelligence and warfare. Images can be in visible colours and in other spectra.

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The rapid development of sensor technology has enabled higher resolutions for the remote sensed images namely the satellite images (e.g. Quick-Bird images have ground resolution of 0.6m). Extensive investigations have been conducted in the past two decades to reliably extract features like roads from these highly accurate images. Satellite imagery can be combined with vector or raster data in a GIS provided that the imagery has been spatially rectified so that it will properly align with other data sets.

To identify roads from high resolution remote sensing images and to distinguish it with other objects like buildings, rivers and woods, the color information, usually in four or more spectral bands can be used as an important feature. Between the diversity of methods, the decision to choose one or other one depends on the balance between speed, accuracy and complexity of the computer algorithm. Even more, such expected accuracy can be related to the quality of input data, in terms of resolution of the digital image. The satellite images can be represented as raster images and digital raster images can be classified as portrayals of scenes, with imperfect renditions of objects. Imperfections in an image result from the imaging system, signal noise, atmospheric scatter and shadows. Thus, the task of identifying and extracting the desired information or features from a raster image is based on a criteria developed to determine a particular feature (based on its characteristics within any raster image), while ignoring the presence of other features and imperfections in the image. Automatic methods of extraction are more complex than Semi-automatic methods of extraction. Automatic methods of extraction require ancillary information, as compared to Semi-automatic methods that extract roads based on information from the input image.

2. Related Works

Semi automated and automated road extraction from satellite images can save time and labour to a great degree in updating road spatial database. Various road extraction approaches have been developed. An Integrated Method for Urban Main Road Centerline Extraction is based on spatial classification to segment the images based on road and non road groups [1]. A multistage framework was designed to extract road networks based on probabilistic SVMs and salient features [2]. Pixel based methods can be based to classify road detection where Edge Detectors can be used to extract potential road points [3]. In the statistical inference method, linear features are modelled as a Markov point process or a geometric-stochastic model on the road width, direction, intensity and background intensity and maximum a posteriori probability is used to estimate the road network [4]. Besides these, active contour models, known as snakes, are also used in semi automatic road extraction [5].

The semi automatic methods of road extraction require some road seeds as starting points, which are in general provided by users and road segments evolve under a certain model. Further, these methods use black-and-white aerial photographs or the panchromatic band of high-resolution satellite images and therefore the geometric characteristics of the roads alone play a critical role. Various road extraction algorithms have been proposed over the past decades. Mena [6] and Das et al. presented overviews of road detection methods in this area. Quackenbush [7] gave a review of linear feature extraction from imagery which can be used for road extraction. Automatic road detection method tests were devised by Mayer et al. [8]. Based on the level of road knowledge used, Poullis and You [9] classified road detection methods into three categories: 1) pixel-based; 2) region-based; and 3) knowledge-based. The pixel-based methods depend on the information obtained from the pixels. Line [10], [11], and ridge [12], [13] detectors are used to extract potential road points. Road points are then connected to produce road segments and also used as input to a higher level processing phase.

Road extraction methods have been proposed by several authors from different viewpoints. Based on homogeneous polygonal areas around each pixel, Hu et al. [14] defined the pixel footprint to extract road areas. Similarly, Zhang et al. [15] applied this detector to extract roads in urban areas. Movaghati et al. [16] applied particle filtering and Kalman filtering to extract road networks. Road intersection extraction from remotely sensed images was also studied [17]–[19]. Although road intersection extraction alone cannot be a complete road network generation, it is useful for understanding road network topologies and higher processing.

In the semi automatic method the active contour model is being employed for the extraction of roads. In the active contour model initial points (seed points) have to be specified from which the roads are detected. Depending on the length of the road to be extracted appropriate seed points have to be given. The idea is to plot the active contour between the seed points. After filtering the image with a Gaussian filter, the potential of the image is being computed and it illustrates the influence of the edges of the information that has to be extracted. Even when the points don't fall in the centre line of the road, they help to the program to get an idea of the direction. So, data between them can be interpolated. Since new initialization snake points are being interpolated, when the distances between the points are larger than an amount of pixels, the order that the user initialize the points is important. This is because it is depended on the direction and distance between these given points to interpolate new points between them. So, the Active Contour algorithm is implemented in a consecutive sequence such that the total segment of the road, within the points selected by the user, will be extracted. The first step is to specify the seed points along the road to be extracted from a given satellite image. The next step is to find the Gradient and Potential of the satellite image which helps in identifying the roads edges. Then the contours are identified through interpolation based on the seed points given by the user. After the contours are identified the next step is to evolve the active contour (snake) along the seed points specified by the user which represents the road surface.

3. Advantages and Disadvantages of the Present Works

In the semi automatic extraction techniques once the initial points or seed points are given which gives a preliminary approximation of the feature and hence feature extraction can be done more accurately. So it gives better results for any type of satellite images. This saves time and human effort in extracting roads from images. The drawback is that manual intervention is needed initially to perform the computation. Approximations have to be provided by the operator. If the points are not given the Interpolation Routine can generate points out of track. With high quality images object identification and feature extraction can be done effectively. It helps in better decision-makings for Urban Planning, Traffic Management and Vehicle Navigation. The Disadvantage is that the output is purely dependent on the Resolution of the images, Input road characteristics and variations.

A given input satellite image pertaining to an ordinary area is shown as follows:

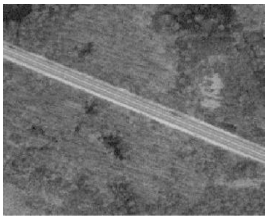

Fig.1. Input Image

Using the Semi automatic method the Gradient of smoothed image and potential is obtained as follows:

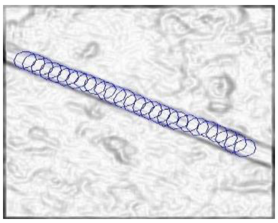

Fig.2. Gradient and Potential

After the Gradient and Potential are obtained, the Active Contour operation is applied.

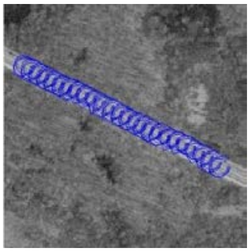

Fig.3. Active Contour

In the Semi Automatic approach the Active Contour detects the road from the given initial seed points.

4. Vectorization Approach to Road Extraction

With the increasing resolution of remote sensing images, road network can be displayed as continuous and homogeneity regions with a certain width rather than traditional thin lines. Therefore, road network extraction from large scale images refers to reliable road surface detection which identifies road segments from the RS Images. A novel automatic road network detection approach based on the combination of segmentation and vectorization is explained, which includes three main steps: (i) the image is segmented to roughly identify the road network regions; (ii) the decision making and continuity procedure to correctly detect the roads and (iii) the Vectorization step to identify the line segments or curved segments which represent the roads segment. Lastly, the results from QuickBird images demonstrate the correctness and efficiency of the proposed process. These steps can be explained using the following flow diagram as shown:

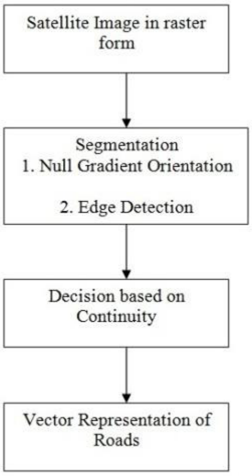

Fig.4. Automated Road Extraction Flow Diagram

The Proposal is to develop an automatic method for road extraction from high resolution satellite images. In the vectorization approach of road extraction no seed points have to be given. The vectorization approach is an automatic method in extracting road segments from satellite images. The method adopted is to identify the road segments which are represented as continuous line segments as the road could be of any arbitrary shape. The start and end points of each line segment is identified and the road segments in the image are correctly extracted. The first stage is to identify the road network regions using segmentation. Then a decision making and continuity procedure is being performed in order to correctly detect the road. As a road may be of different shapes like straight roads or curved ones the vectorization step identifies the line segment which corresponds to the road. The method automatically identifies the road segments in a high resolution satellite image where the output is highly dependent on the image.

The first stage of the automatic method is to classify the road from the given satellite image using segmentation which consist of two stages namely the Null Gradient Orientation method and the Edge Detection method. The Null Gradient Orientation method finds out the gradient at all pixels and then the eigen transform is being performed on the tensor and the result is such that there will be two eigen values and two eigen vectors. The method is to choose those pixels for which at least one eigen value has a minimum which corresponds to a road. And also the Eigen vector corresponding to minimum Eigen value gives the direction of road. The next stage is the edge detection using the Canny Operator which identifies the edges which shows superior results compared to other edge detection methods. Also two threshold values are fine tuned so that the small connected elements are rejected and only the large connected areas are chosen. In the second stage the task is to detect the line segments and the Hough Transform is being used to detect the line segments. The final stage is the vectorization step where the road segments are clearly identified from the High Resolution Satellite Image.

4.1. Image Segmentation

In computer vision, segmentation refers to the process of partitioning a digital image into multiple segments (sets of pixels, also known as super-pixels). The goal of segmentation is to simplify and/or change the representation of an image into something that is more meaningful and easier to analyze. Image segmentation is typically used to locate objects and boundaries (lines, curves, etc.) in images. More precisely, image segmentation is the process of assigning a label to every pixel in an image such that pixels with the same label share certain visual characteristics. The result of image segmentation is a set of segments that collectively cover the entire image, or a set of contours extracted from the image (see edge detection). Each of the pixels in a region is similar with respect to some characteristic or computed property, such as color, intensity, or texture. Adjacent regions are significantly different with respect to the same characteristics.

4.2 Null Gradient Orientation

The Gradient of a function of two variables F(x,y) can be defined as

$$\nabla F = \frac{\partial F}{\partial x}\hat{i} + \frac{\partial F}{\partial y}\hat{j} \tag{1}$$

The above equation can be collected as a collection of vectors pointing in the direction of increasing values of F. The numerical gradients (differences) can be computed for functions with any number of variables. For a Function of N variables F(x,y,z,…) the gradient can be computed as

$$\nabla F = \frac{\partial F}{\partial x}\hat{i} + \frac{\partial F}{\partial y}\hat{j} + \frac{\partial F}{\partial z}\hat{k} + ... \tag{2}$$

The description for the above equations can be given as: FX = gradient (F) where F is a vector returns the one-dimensional numerical gradient of F. FX corresponds to $\partial F/\partial x$, the differences in the x (column) direction. FY corresponds to $\partial F/\partial y$, the differences in the y (row) direction. The spacing between points in each direction is assumed to be one. [FX,FY,FZ,...] = gradient(F) where F has N dimensions returns the N components of the gradient of F. There are two ways to control the spacing between values in F:

A single spacing value, h, specifies the spacing between points in every direction. N spacing values (h1,h2,...) specifies the spacing for each dimension of F. Scalar spacing parameters specify a constant spacing for each dimension. Vector parameters specify the coordinates of the values along corresponding dimensions of F. In this case, the length of the vector must match the size of the corresponding dimension. In vector calculus, the gradient of a scalar field is a vector field which points in the direction of the greatest rate of increase of the scalar field and whose magnitude is the greatest rate of change. The property of Road is that there is continuity in one direction. So the method adopted is to find the Gradient at all pixels. The Gradient is then represented as a Tensor. Eigen Transforms are being performed on the Tensor which consists of two eigen values and two eigen vectors. The idea is to choose those pixels for which at-least one eigen value has a minimum value which corresponds to a road. Also the eigen vector corresponding to minimum eigen value gives the direction of road.

4.3 Edge Detection

Edge detection is a fundamental tool in image processing and computer vision, particularly in the areas of feature detection and feature extraction, which aim at identifying points in a digital image at which the image brightness changes sharply or more formally has discontinuities. In the ideal case, the result of applying an edge detector to an image may lead to a set of connected curves that indicate the boundaries of objects, the boundaries of surface markings as well as curves that correspond to discontinuities in surface orientation. Thus, applying an edge detection algorithm to an image may significantly reduce the amount of data to be processed and may therefore filter out information that may be regarded as less relevant, while preserving the important structural properties of an image. If the edge detection step is successful, the subsequent task of interpreting the information contents in the original image may therefore be substantially simplified. However, it is not always possible to obtain such ideal edges from real life images of moderate complexity. Edges extracted from non-trivial images are often hampered by fragmentation, meaning that the edge curves are not connected, missing edge segments as well as false edges not corresponding to interesting phenomena in the image – thus complicating the subsequent task of interpreting the image data.

The edge detection algorithm being employed is the Canny Edge Detection Algorithm which consists of multi stages.

The algorithm runs in 5 separate steps:

- Smoothing: Blurring of the image to remove noise.
- Finding gradients: The edges should be marked where the gradients of the image has large magnitudes.
- Non-maximum suppression: Only local maxima should be marked as edges.
- Double thresholding: Potential edges are determined by thresholding.
- Edge tracking by hysteresis: Final edges are determined by suppressing all edges that are not connected to a very certain (strong) edge.

4.4 Decision Making based on Continuity

A lot of edges are proved not to be roads through the procedure of edge detection. Therefore road following or tracking is one of the most important steps in road detection. The major goal of road tracking is to eliminate road-like but non-road pixels. Hough Transforms are being used to perform this step. In automated analysis of digital images, a sub-problem often arises of detecting simple shapes, such as straight lines, circles or ellipses. In many cases an edge detector can be used as a pre-processing stage to obtain image points or image pixels that are on the desired curve in the image space. Due to imperfections in either the image data or the edge detector, however, there may be missing points or pixels on the desired curves as well as spatial deviations between the ideal line/circle/ellipse and the noisy edge points as they are obtained from the edge detector. For these reasons, it is often non-trivial to group the extracted edge features to an appropriate set of lines, circles or ellipses. The purpose of the Hough transform is to address this problem by making it possible to perform groupings of edge points into object candidates by performing an explicit voting procedure over a set of parameterized image objects.

4.5 Vector Representation of Roads

Vector graphics is the use of geometrical primitives such as points, lines, curves, and shapes or polygon(s), which are all based on mathematical equations, to represent images in computer graphics. Vector graphics formats are complementary to raster graphics, which is the representation of images as an array of pixels, as it is typically used for the representation of photographic images. Computer displays are made up from grids of small rectangular cells called pixels. The picture is built up from these cells. The smaller and closer the cells are together, the better the quality of the image, but the bigger the file needed to store the data. If the number of pixels is kept constant, the size of each pixel will grow and the image becomes grainy (pixellated) when magnified, as the resolution of the eye enables it to pick out individual pixels.

Vector graphics files store the lines, shapes and colours that make up an image as mathematical formulae. A vector graphics program uses these mathematical formulae to construct the screen image, building the best quality image possible, given the screen resolution. The mathematical formulae determine where the dots that make up the image should be placed for the best results when displaying the image. Since these formulae can produce an image scalable to any size and detail, the quality of the image is limited only by the resolution of the display, and the file size of vector data generating the image stays the same. Printing the image to paper will usually give a sharper, higher resolution output than printing it to the screen but can use exactly the same vector data file.

5. Results

The vectorization approach is an automatic method in extracting road segments from satellite images. The method adopted is to identify the road segments which are represented as continuous line segments as the road could be of any arbitrary shape. The start and end points of each line segment is identified and the road segments in the image are correctly extracted.

For the above given high resolution satellite image, the output obtained is as follows:

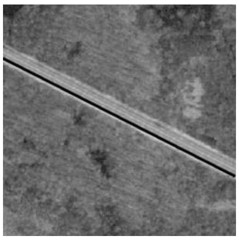

Fig.5. Output Image

The output obtained shows that the image is a tile from mapped data set. The method successfully extracted the road and represented it with just a single line segment. The method gave the correct results as there were no occlusions in the road.

6. Conclusion

In the automatic method of road extraction no seed points have to be given. The method automatically identifies the road segments in a high resolution satellite image where the output is highly dependent on the image. This method is more suited in rural areas than in urban areas where man-made objects are less and it is possible to detect the roads more easily. Through the segmentation, decision making based on continuity and vectorization procedure the raster satellite images can be converted to vector representation and it is possible to extract roads from satellite images. In the case of complex road structures and also in the case of occlusions the semi automated method gave better results than an automated method. The significance of the automated method is that human labour can be minimized to a very large extent. For a real large scale road extraction work, a combination of both methods is being proposed. The first stage employs the utility of the automatic method where the road segments are identified and for identifying the missing parts of the road the semi automatic method is being employed. The combination of both the methods will save time as well as reduce human labour to a very large extent.

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