Resolution Enhancement and Road Extraction for Urban and Sub-urban Management

Deepthy Mary Alex, Bindu K.R, Reemamol P.K

Abstract— As time clicks away, the growth of population is increasing. The needs and requirements of the people are also increasing. Man desires to meet his needs and requirements efficiently and effectively with less cost and time. Due to population growth, the management of urban and sub-urban areas effectively and efficiently is required. The key tool for the same is satellite images and the element in the satellite images are the roads. Road extraction plays a vital role in the management of urban and sub-urban areas. Some applications are GIS updating, traffic management, disaster management and GPS applications. In this paper, roads are extracted from low resolution satellite images. Initially, the satellite images are enhanced using interpolation of high frequency sub-bands of discrete wavelet transform (DWT) and low resolution satellite image. The enhanced image is then processed to extract roads. The two methods used to extract roads are Level Set and Mean Shift method. The performances of both methods are also evaluated.

Index Terms— Clustering, Interpoaltion, Level Set, Mean Shift, Median Filtering, Nearest Neighborhood Grouping, Resolution Enhancement

1 Introduction

IN the recent years there have been many techniques introduced to manage the urban and sub-urban areas. The need for management of these areas sufficiently and effectively is high. The satellite images can be used for managing these areas effectively. Roads of the urban and sub-urban areas play a vital role in the management of these areas. The road extraction also has application like detection of bridges, isolated areas and difficult to reach regions. The main applications in urban and sub-urban management are traffic management, disaster management, GIS updating and GPS applications.

Many techniques have been introduced to extract roads from satellite images but these satellite images used are high resolution satellite images and thus, the cost is quite high. In this paper, road extraction is done from low resolution satellite images. The cost compared to implement this paper is quite low relative to the existing papers.

In this paper, road extraction is done on low resolution satellite images after resolution enhancement using interpolation of high frequency sub-bands of DWT and low frequency satellite image. In this way roads can be extracted efficiently at less cost. The two methods of road extraction explained in this paper are Level set and Mean Shift method. Level set method is an algorithm used to determine the propagating fronts using a speed function. The main criterion to be maintained is that the speed function should be always greater than zero. When considering the Mean shift method, it is a clustering technique used to classify datainto various categories. The advantage of using this method is that no information about specific objects is required. The performances of both algorithms are given in the later pages of this paper. Inorder to get a better idea about level set and mean shift methods, there are papers based on Level Set [1] and Mean Shift [2] in the literature.

Many techniques were also used for resolution enhancement of images earlier. According to Robert G. Keys in [3], Cubic convolution interpolation was derived from a set of conditions which were applied on the interpolation kernel. Interpolation kernels are usually created to maximize the accuracy for a given level of computation factor. Initial approximation to high resolution [HR] in [4] is also a resolution enhancement technique. The method generates the enhanced image using zero padding. It uses zero padded versions of the high frequency sub-bands in the wavelet domain. Another technique is the Inter sub-band correlation in wavelet domain in [5]. It uses correlation of sub-bands with different sampling phases in DWT. The limitations of these techniques are: the images obtained are not sharp as required for further road extraction processes. The PSNR of these techniques are not as desired.

During the past years different techniques have been implemented in road extractions but of all the methods explained in [6], [7], [8], [9] roads are extracted from high resolution satellite images. Better techniques for road extraction are explained in this paper. Level set and Mean shift methods are better efficient than the existing techniques.

The objective of this paper is to provide a robust, efficient and less costly technique to manage the urban and sub-urban areas. The algorithms implemented have less computing time computing time compared to the methods in the literature.

In section 2, the algorithms implemented are explained, in the 3rd section results of the paper implemented is given and the last section gives the conclusion and future scope.

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2 METHODOLOGY

Resolution enhancement based on interpolation of high frequency sub-bands and low resolution satellite image have high PSNR and also Level set and Mean shift methods have an edge over other road extraction methods. Level set is a powerful tool as it extracts roads by taking the road extraction as a boundary evolution problem. Mean shift method is also a powerful tool for road extraction.

2.1 Basic Steps

The basic steps involved in the road extraction from low resolution satellite images are given in fig1. Each block are explained in detail.

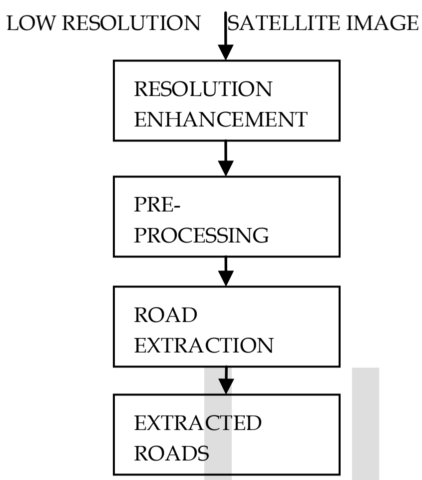

Fig.1 Basic Block Diagram

2.2 Resolution Enhancement

Interpolation is the key tool in resolution enhancement. Interpolation can be simply defined as increasing the number of pixels in an Image. There are basically three types of interpolation. They are classified as nearest neighbor interpolation, bicubic interpolation and bilinear interpolation. Bicubic interpolation is better out of the three as it produces smoother edges. Since resolution enhancement plays vital role on the performance of roads extracted, the loss of image after being enhanced by applying interpolation has to be rectified. The loss is incurred on the high frequency components of the image. Thus, DWT is employed to preserve the high frequency components [10]. The basic block diagram of the enhancement technique employed is given in fig2. Inorder to obtain the maximum output, the low resolution input image is interpolated with a interpolation factor $\alpha/2$ instead of low frequency sub-bands which contain less information compared to the low resolution input image. DWT separates the low resolution satellite image into different sub-bands. The different sub-bands are LL, LH, HL, HH. The low resolution satellite image and the interpolated LL sub-band are highly correlated to obtain a better sharp image. The difference between the low resolution satellite image and the LL sub-band image occurs in their high frequency components and thus, their difference can be used to correct the estimated high frequency components. The estimation can be done by interpolating the high frequency sub-bands by a factor 2 and then include the difference image into the high frequency images. Finally another interpolation with factor $\alpha/2$ is carried out to reach the required size for IDWT.

The process of adding the difference image containing the high frequency components generates sharper and clearer enhanced satellite image.

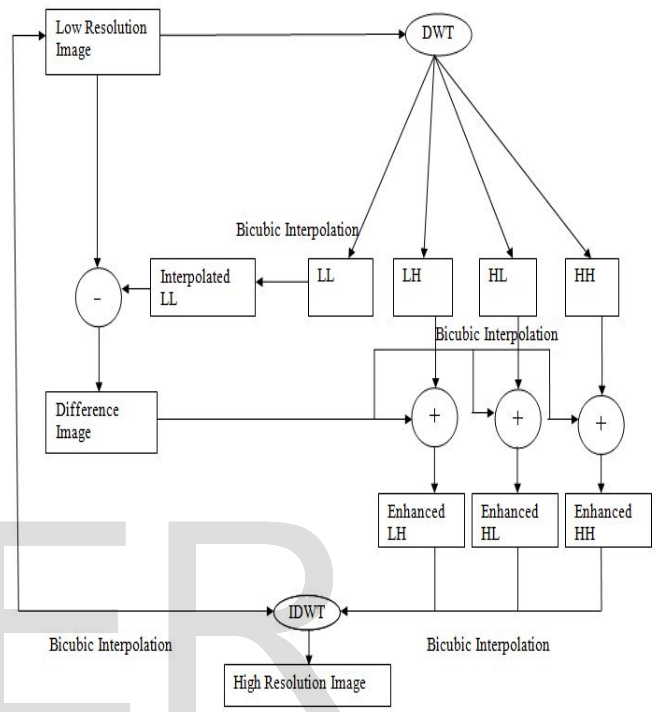

Fig.2 Block Diagram of Resolution Enhancement

2.3 Pre-processing

This step is done inorder to refine the enhanced image to some extend before doing the road extraction. By doing preprocessing many unwanted objects or pixels can be eliminated. Thus, the tolerance can be increased thereby minimizing the effects of high resolution images. Some of the effects are road marking, occlusions, shadows of trees and buildings. The three steps involved in pre-processing are classification, grouping and filtering.

- Classification: The input to this step is the enhanced satellite image. By setting an appropriate threshold, Otsu clustering is done on the satellite image. Clustering can be defined as as grouping of an entire image into small clusters on the basis of a particular parameter. In Otsu clustering, clustering is done on the basis of the variances of the foreground and the background.
- Grouping: Grouping is basically done to eliminate small patches of road contrast abnormalities and vehicular occlusions. The type of grouping done here is Nearest neighborhood grouping (NNG). It improves the spectral response within the pixel's local neighborhood. The grouping is done

by considering the eight neighbors of a particular pixel in the image. The centre pixel is replaced by the pixel intensity value that occurs four or more number of times in its eight neighborhood. Otherwise the original pixel intensity value is retained by the centre pixel.

- Filtering: Even after carrying out clustering and grouping, there are still disterubances such as reflectance of old buildings that resembles road surface and also since satellite images get affected by noise during capturing and processing, filtering has to be done. The best filter that can be considered when satellite images are in question is the median filter [11]. The median filter used in this paper is a filter having 5X5 window.

2.4 Road Extraction

Road extractions are done using two recent techniques in study.

2.4.1 Level Set Method

The main aim of level set method is to track the evolution of a propagating boundary front with a speed function that is normal to the boundary curve. For extraction roads in the image are assumed as boundaries. Inorder to extract roads using this method, the speed function should be greater than zero at the edges of the boundary. Roads are extracted on the basis of the internal and external energy. The aim of internal energy is to avoid or prevent the deviation of ф from the signed distance function during the evolution of boundaries and the aim of external energy is to direct the level set towards the edge boundary. The function phi (ф) is initialized such that the propagating fronts denoted by C are represented using zero level set as

$$C(\mathrm{t}) = \{(\mathrm{x},\mathrm{y}) \mid \Phi(\mathrm{t},\mathrm{x},\mathrm{y}) = 0\} \quad (1)$$

The edge indicator function g is given as

$$g = \frac{1}{1 + \left|\nabla G_\sigma \times I\right|^2} \quad (2)$$

where I is the enhanced image and G_σ is the Gaussian kernel with standard deviation σ. The external energy for the function ф(x,y) is given as

$$\varepsilon_{g,\lambda,v}(\phi) = \lambda \mathrm{L}_g(\phi) + \mathrm{v}\mathrm{A}_g(\phi) \quad (3)$$

where λ and v are constants and they are greater than zero and the terms L_g(ф) and A_g(ф) are given as

$$\mathrm{L}_g(\phi) = \int_\Omega g\delta(\phi)\left|\nabla\phi\right| dxdy \quad (4)$$

and

$$A_g(\phi) = \int_\Omega gH(-\phi)dxdy \quad (5)$$

respectively. In (4) and (5), the parameters δ is the univariate Dirac function and H is the Heaviside function respectively.

The total energy used in Level set method is given by the equation

$$\varepsilon(\phi) = \mu\,\mathrm{P}(\phi) + \varepsilon_{g,\lambda,v}(\phi) \quad (6)$$

the first term in (6) on the right hand side is the internal energy. By taking the Gateaux derivative of (6), we get

$$\frac{\partial\varepsilon}{\partial\phi} = -\mu[\Delta\phi - \mathrm{div}(\frac{\nabla\phi}{|\nabla\phi|})] - \lambda\delta(\phi)\,\mathrm{div}(\mathrm{g}\frac{\nabla\phi}{|\nabla\phi|}) - \mathrm{vg}\,\delta(\phi) \quad (7)$$

where Δ is a Laplacian operator. But we know that

$$\frac{\partial\phi}{\partial t} = -\frac{\partial\varepsilon}{\partial\phi} \quad (8)$$

Thus, (7) can be written has

$$\frac{\partial\phi}{\partial t} = \mu[\Delta\phi - \mathrm{div}(\frac{\nabla\phi}{|\nabla\phi|})] - \lambda\delta(\phi)\,\mathrm{div}(\mathrm{g}\frac{\nabla\phi}{|\nabla\phi|}) - \mathrm{vg}\,\delta(\phi) \quad (9)$$

The gradient flow is represented using (9). Equation (9) is iterated till the gradient flow is zero. When zero is attained, all the roads in the image are attained.

2.4.2 Mean Shift Method

The main idea of Mean shift method is unsupervised clustering. Initially select random data points Xi such that i=1,2..n, in a d-dimensional space Rd. The kernel density estimation at each locations of X is calculated using (10).

$$\overline{f}_K(\mathrm{x}) = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{h_i^d}k\left(\left\|\frac{x - x_i}{h}\right\|^2\right) \quad (10)$$

The bandwidth parameter in (10) is represented using hi and kernel is represented using K. Kernel satisfies the bounded support as it is spherically symmetric.

$$K(\mathrm{x}) = \mathrm{c}_{k,d}\, k(\|x\|^2) > 0 \quad \|x\| \le 1 \quad (11)$$

$C_{k,d}$ in (11) denotes normalization constant and it affirms that K(x) integrates to one. The profile of the kernel is represented using k(x) and on assuming that derivative of the profile exists, we can define a kernel G(x). Taking g(x)=-k'(x) as the kernel, then G(x) is given as

$$\mathrm{G}(\mathrm{x}) = \mathrm{c}_{\mathrm{g},d}\,\mathrm{g}(\|x\|^2) \quad (12)$$

The mean shift vector used to extract roads is given in (13). The vector points in the direction where there is maximum density increase. Inorder to extract roads using Mean shift method, the mean shift procedure containing mean shift vector and translation of kernel G(x) has to done successively until the gradient becomes zero by converging to a point.

$$m_{h,G}(\mathrm{x}) = \frac{\sum_{i=1}^{n} x_i g\left(\left\|\frac{\mathrm{x}-\mathrm{x}_i}{h}\right\|^2\right)}{\sum_{i=1}^{n} g\left(\left\|\frac{\mathrm{x}-\mathrm{x}_i}{h}\right\|^2\right)} - x \quad (13)$$

The number of iterations required for the extraction is given by the equation (14).

$$y_{j+1} = \frac{\sum_{i=1}^{n} \frac{x_i}{h_i^{d+2}} g\left(\left\|\frac{y_j-\mathrm{x}_i}{h}\right\|\right)}{\sum_{i=1}^{n} \frac{1}{h_i^{d+2}} g\left(\left\|\frac{y_j-\mathrm{x}_i}{h}\right\|^2\right)} \quad \text{j=1,2..n} \quad (14)$$

Inorder to calculate (14), the starting position of the kernel can be set has any one of the points Xi.

2.5 Image overlaying

To express the output obtained clearly and in a better way, the extracted roads are overlaid onto the grayscale image of the enhanced multispectral image. By doing so, the complex noise can be eliminated or avoided to a great extend.

2.6 Analysis of Performance

The performances are analysed by comparing the roads obtained by implementing the algorithm with manually extracted roads. The different parameters [12] on which the performance depends are

$$\text{Completeness}=\frac{\mathrm{TP}}{\mathrm{TP}+\mathrm{TN}} \quad (15)$$

$$\text{Correctness}=\frac{\mathrm{TP}}{\mathrm{TP}+\mathrm{FN}} \quad (16)$$

$$\text{Quality}=\frac{\mathrm{TP}}{\mathrm{TP}+\mathrm{FP}+\mathrm{FN}} \quad (17)$$

$$\text{Redundacy}=\frac{\mathrm{TP\text{-}[1\text{-}FP+FN]}}{\mathrm{TP}} \quad (18)$$

where TP(true positive) occurs when the derived result coincide with the reference, TN(true negative) occurs when the derived result doesn't coincide with the reference, FP(false positive) is when there is a road pixel in the derived result that is not present in the reference and FN(false negative) is when there is a road pixel in the reference that is not present in the derived result.

Completeness is used to express the percentage of correctly extracted reference data while correctness expresses the percentage of correctly extracted roads. The completeness of extraction refers to producer's accuracy and correctness of extraction refers to user's accuracy. The overall accuracy of extraction can be termed as quality. The roads that overlap corresponding to the ideal roads can be in expressed in percentage as redundancy.

3 Result and Discussion

The algorithms for road extraction from a low resolution satellite image was developed and tested on some images. To analyse the performances of both the road extraction methods, certain parameters were calculated and compared using manually traced reference roads. The output of each stage is shown in fig3.

The algorithms were implemented using MATLAB 7.10 tool. The input image used is a Low resolution satellite image and from the performance analysis,we can say that Mean shift method is a little better than Level Set method eventhough the computation time and redundancy are more and less respectively than level set. The performance analysis of image in fig3 is given in table 1. The outputs obtained gave a good and effective result but the performance strongly depends on the application at hand and there can be situations when the algorithms may not render the desired results as it so in case of image processing.

TABLE 1
Analysis of Performance

Performance Parameters	Level Set method	Mean Shift method
Completeness	91.4699	93.8768
Correctness	92.9796	96.6271
Quality	91.4699	93.8768
Redundancy	1.0577	1.0046
Computation time	21.0003 seconds	30.1351 seconds

The low resolution satellite image used in this paper is an image of a sub-urban area. The initial size of the image is 66X77 pixels and the image is a multispectral image. A multispectral image is an image that has more three spectral bands, in the current image; the spectral bands are red, green and blue. The roads in the overlaid images are denoted by white color or 255 pixel intensity value.

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(a)

(b)

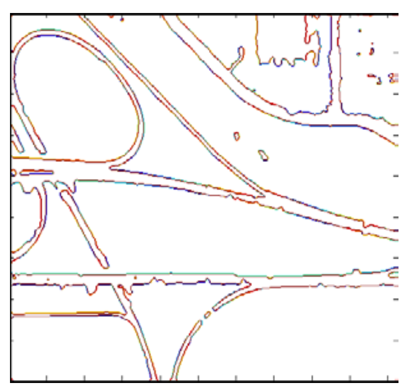
(c)

(d)

(e)

(f)

(g)



(h)

(i)

Fig.3 Outputs at different stages

(a) Low resolution image (b) Enhanced image (c) Clustered image (d) Grouped image (e) Filtered image (f) Roads using Level set (g) Level set overlaid image (h) Roads using Mean shift method (i) Mean shift overlaid image

4 Conclusion and Future Scope

Road Extraction is of fundamental importance for the urban and sub-urban planners to manage the ever-changing urban and sub-urban environment. For the proposed paper, program was developed for road extraction from Low resolution satellite images using two methods. The two methods of road extraction were Level set method and Mean shift method. The algorithm was implemented to detect highways and roads from Low resolution multispectral satellite images. The algorithm was tested with several images. The resolution enhancement in the initial stage for desired output is done using Bicubic interpolation high frequency sub-bands obtained from DWT and the low resolution input image. In the results we can say that most of the highways were detected, but in some cases, small parts of barren land and parking lots were also classified as roadways. The detection of some unwanted objects is because the techniques are based on the propagating boundary fronts and clustering respectively. Inorder to improve the algorithm results, the following can be considered. Level set method has to be refined to extract the unidentified road regions and the Mean Shift method has radically symmetric kernels. Hence the change in the road width requires an adjustment of the kernel bandwidth to consistently track the road. While considering the algorithm used for resolution enhancement, the algorithm has limited implementation only for multiple frames. It cannot be used for a single frame. Further it is applicable only for symmetric images. Here two frames are considered. This algorithm can be extended for more number of frames with any arbitrary sub-pixel shift.

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