SEMI-AUTOMATIC EXTRACTION OF DIFFERENT-SHAPED ROAD CENTERLINES FROM MS AND PAN-SHARPED IKONOS IMAGES

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ABSTRACT:

In this work we develop semi-automatic road extraction system for updating and storage road network data bases. Combination of some of the existing road extraction techniques such as spectral and spatial data clustering, morphological functions and graph theory is used in this proposed system.

Input data of the proposed road extraction system are multi-spectral and pan-sharpened IKONOS images of Lavasan city in Iran (with respectively 4 and 1 meters spatial resolution). The proposed system investigates capability and amount of system success in extraction of different shaped roads such as straight, spiral, junction and square.

In the proposed method, primarily the input image is spectrally classified by use of Fuzzy C-Means (FCM) clustering technique and road class binary image is obtained by definition of threshold value. Afterwards, quality of detected road features is improved using morphological operators like dilation, erosion, opening, closing, bridge and etc. Our approach proceeds by performing spatial cluster analysis using C-Means technique and hence, road centerline nodes are attained. Finally by use of graph theory and minimum spanning tree (MST) and defining an appropriate cost function, these key points are connected and vector road centerline is obtained.

The only drawback of this system is limitation in completely extraction of road centerline in place of squares and closed loops.

Attaining mean overall accuracy (OA) of 98.2% and Kappa coefficient of 86.26% in classification of image to road and non-road classes, and also mean RMS error of 0.64 pixel in comparing automatic extracted road centerline with manual extracted one, are a good criterion of proposed system success in semi-automatic extraction of roads.

1. INTRODUCTION

Attaining geospatial information is a challenging issue for many scientists and experts in the field of spatial decision making. Feature extraction from aerial or satellite images is a supplemental technology to achieve these kinds of information and is able to facilitate image analysis and interpretation and updating existing databases which are one of the urgent requirements of each organization. At present, information extraction from images is performed mostly manually, and thus time and cost intensive. To overcome this drawback, automatic methods for extraction of information and analysis of image content are needed.

On the other hand, the advent of high resolution optical satellite imagery such as IKONOS or Quickbird, creates new possibilities for the extraction of linear features such as roads. The advantages of this digital data compared to aerial imagery are the worldwide availability and higher radiometric resolution in fewer spectral bands. The worldwide availability of the satellite digital data makes it possible to produce topographic databases for nearly any region of the earth and for extensive applications such as military purposes, disaster managements, crop and weather predictions, traffic managements and etc. Although the geometric resolution of HR satellite images are often worse than that of the aerial images, but for the purpose of road extraction and updating spatial data bases is generally sufficient.

The most prominent linear topographic features to be extracted from satellite images are roads. Roads are important large networks that seem to be the most vital transportation arteries of each country which extraction of them has been one of popular research areas in computer vision, remote sensing, photogrammetry and GIS communities. Therefore many efforts have been performed to extract them from digital images.

An inclusive review on the proposed methods of road extraction could be found in (Mena, 2003). In (Long and Zhao, 2005) a new integrated system for automatic extraction of main roads from high resolution satellite images was presented which used multi-scale gray level morphological cleaning algorithm to reduce road gray level deviation and the binary image was analyzed by morphological operators and convex hull algorithms.

The research presented in (Wang et al., 2005), showed that by utilizing the texture, edge, shape and size properties, non-road pixels could be removed in order to improve road detection results.

The idea of geometrical and topological analysis of high resolution binary images for automatic vectorization of segmented road networks was presented in (Mena, 2006).

(Mohammadzadeh et al., 2006) proposed a new fuzzy segmentation method for road detection in high resolution satellite images that needed only a few number of road samples. Then using an advanced mathematical morphological operator, road centerlines were extracted. Also, in (Zhang and Couloigner, 2006), the effectiveness of angular texture signature was evaluated to discriminate between parking lots and roads using high resolution satellite images.

According to necessity and importance of using accurate and update spatial information of road network for traffic management, automatic vehicle navigation, natural hazard assessment and critical decision making, using automatic,

robust, and computationally feasible road detection algorithms is essential.

In this research we develop semi-automatic road extraction system for updating and storage road network data bases and to reduce charges and also keeping or increasing precision and speed of information extraction in comparison with field work and GPS usage. Combination of some of the existing road extraction techniques such as spectral and spatial data clustering, morphological functions and graph theory is used in this proposed system.

In the proposed system, primarily the input images that are multi-spectral and pan-sharpened IKONOS images of Lavasan city in Iran (with respectively 4 and 1 meters spatial resolution), are spectrally classified by use of Fuzzy C-Means (FCM) clustering technique and road class binary image is obtained by definition of threshold value. This technique (FCM) tests different distance function types in performing FCM clustering and finds the most precise and fastest one. Afterwards, quality of detected road features is improved using morphological operators. Our approach proceeds by performing spatial cluster analysis using k-means technique and hence road center line nodes are attained. In this step, effect of choosing different number of cluster centers in spatial domain for comprehensive road shape estimation is investigated. Finally by use of graph theory and minimum spanning tree (MST) and defining an appropriate cost function, these key points are connected and vector road centerline is obtained. These road vectors can be directly imported into GIS environment in different formats for updating digital road maps.

The main achievement of the proposed system is extraction of different shaped roads such as straight, spiral, junction and square and attaining acceptable precisions in order to updating road maps. The only drawback of this system is limitation in completely extraction of road center line in place of squares and closed loops. So supervision of human operator for completing missed links and closing the loops is inevitable.

This paper consists of five sections. After this introduction, Section 2 describes c-means and FCM clustering algorithms, morphological operators and MST algorithms as part of the background information. Section 3 presents in detail the proposed semi automatic road extraction algorithm. Section 4 provides some experimental results of application of the proposed algorithm to image data. Conclusions are given in Section 5.

2. BACKGROUND

2.1 C-Means and FCM Clustering Techniques

There are several methods for segmenting images based on two fundamental properties of the pixel values: One of them is "discontinuity" that uses the discontinuities between gray-level regions to detect isolated points, edges and contours within an image. The other is "similarity" that uses decision criteria to separate an image into different groups, based on the similarity of the pixel levels. Clustering is one of the methods of second category.

While there are many different algorithms for clustering, this paper focuses on the two well-known clustering algorithms for classification of image in spatial and spectral domain; c-means and fuzzy c-means (FCM) clustering.

K-means Clustering

The K-means algorithm is one of the most popular iterative descent clustering methods. It is intended for situations in which each object belongs to one class exclusively. The K-means method is numerical, unsupervised, non-deterministic and iterative.

In this kind of clustering the dataset is partitioned into K clusters and the data points are randomly assigned to the clusters. Then for each data point the distance to each cluster is calculated and the data point is moved into closest cluster. These steps are repeated until no data point is moved from one cluster to another. At this point the clusters are stable and the clustering process ends. For more information about K-means technique see (Hung, 2005).

Fuzzy C-Means Clustering (FCM clustering)

Among the various clustering algorithms, FCM is one of the most popular methods used in data analysis since it is suited to deal with imprecise and uncertain nature of image data sets, such as remote sensing images.

This technique offers the opportunity to deal with data that belong to more than one cluster at the same time. Most of the fuzzy clustering algorithms are objective function based. They make an optimal classification by minimizing an objective function. In objective function based clustering usually each cluster is represented by a cluster model. This model consists of a cluster center and maybe some additional information about the size and the shape of the cluster. The extension of the cluster in different directions of the underlying domain is determined by the size and shape parameters.

The degrees of membership of each data point in different clusters are computed from the distances of the data point to the cluster centers by considering the size and the shape of the cluster as stated by the additional model information. The closer a data point is to the center of a cluster, the higher is its degree of membership to this cluster. So the division of a dataset into c clusters can be stated as the minimization of the distances of the data points to the cluster centers, since, of course, we want to maximize the degrees of membership.

The Fuzzy C-means (FCM) algorithm proposed by Bezdek is an unsupervised clustering technique, aims to find fuzzy partitioning of a given training set, by minimizing of the basic c-means objective function. For more information about FCM technique, see (Hoppner, 1997; Modenesi et al., 2006; Dave, 1989)

2.2 Morphological Functions

The word morphology commonly denotes a branch of biology that deals with the form and structure of animals and plants. We use the same word here in the context of mathematical morphology as a tool for extracting image components that are useful in image representation and description of region shape, such as boundaries, skeleton and the convex hull. We are interested also in morphological techniques for pre- or post processing (Gonzalez, 2002).

The language of mathematical morphology is set theory. Different morphological operators are made using structural elements. Structural elements are the basic component of the morphological functions that define the neighbourhood of the image pixels by using 1 and 0 values.

By combining set theory rules by logical operators, different morphological functions are made such as Dilation, Erosion,

Opening & Closing, Hit-or-Miss Transformation and etc. for getting more information about morphological functions and algorithms and their applications see (Gonzalez, 2002).

2.3 MST Algorithms

Given a connected, undirected and weighted graph G=(V,E), a Minimum *Spanning Tree T* is a connected sub graph of G such that there is no cycle in T and the edges in T create a path between any two nodes in G, and the sum of the weights of the edges in T is minimized.

The most prominent MST algorithms are Kruskal and Prime which are considered Greedy algorithms.

In each phases of "Greedy algorithms, a decision is made that appears to be good, without regard for future consequences. Generally, this means that some *local optimum* is chosen. This strategy is the source of the name for this class of algorithms. When the algorithm terminates, we hope that the local optimum is equal to the *global optimum*. If this is the case, then the algorithm is correct; otherwise, the algorithm has produced a suboptimal solution. Both of these algorithms find the optimal solution of the problem but in different methods. Kruskal algorithm finds MST based on edges but Prime algorithm find MST based on Vertices, But both of them have the same result.

Since in this research Kruskal algorithm has been used, this algorithm is introduced.

Kruskal algorithm was initially presented by Juseph Kruskal in 1965. steps of This algorithm are as follows:

1. Find the cheapest edge in the graph (if there is more than one, pick one at random).

2. Find the cheapest unmarked edge in the graph that doesn't close a cycle.

3. Repeat Step 2 until you reach out to every vertex of the graph (or you have N Vertices and N-1 edges, where N is the number of Vertices.

Designing variety of networks like phone lines, Electronic and hydraulic lines, TV cables, computer and road networks are the Main applications of MST

3 APPROACH

In order to better understanding of the proposed road extraction system implementation, Figure 1 denotes the diagram of it. Using these diagram, different procedures of the proposed system can be described as follows:

3.1 Input Images

Input data of the proposed road extraction system are multi-spectral and pan-sharpened IKONOS images of Lavasan city in Iran (with respectively 4 and 1 meters spatial resolution). The proposed system investigates capability and amount of system success in extraction of different shaped roads such as straight, spiral, junction and square. No additional data is used for implementation of the system except for what is mentioned.

Figure 2 represents the IKONOS tested images of Lavasan city in Iran (with respectively 4 and 1 meters spatial resolution).

3.2 Pre-processing of Images

Image enhancement in order to modifying the value of image pixels, is a classical method for improving the visual perception. In this research Linear Histogram Stretching

technique using PCI Geomatica V9.1 software is used for preprocessing of the images when it is needed. By using this method. Image gray level values are transformed from observation domain to complete dynamic domain using linear transform function.

Although the processed image is more suitable than the original image for some applications, in classification application (that is used in this research) it is suggested not to use this technique as much as possible. Because changing the gray level values may mislead the classification procedure.
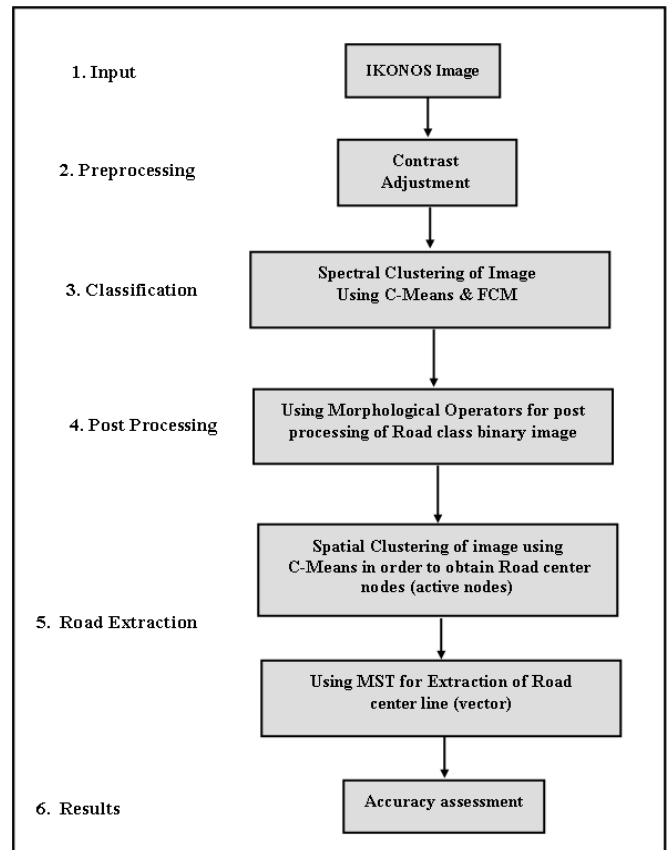

Figure 1. Semi- automatic road extraction Diagram

(a)

(b)

(c)

Figure 2. Multi-spectral and pan-sharpened IKONOS images of Lavasan city in Iran (Input images)

3.3 FCM Clustering in Spectral Domain

In this step of proposed algorithm, FCM clustering technique is implemented by defining number of cluster centers (C) and fuzzy parameter m in spectral space. in this work, cluster centers were not selected randomly. For definition of cluster centers, at first C-Means clustering technique was done by defining C and the output of this technique were entered the FCM as input cluster centers. The number of cluster centers (C) is defined according to diversity of image objects and by try and error operation.

After performing the clustering technique, by supervision of human expert and definition of suitable threshold, road class binary image is obtained.

3.4 Post-processing of Images

After selection of road class binary image, since the obtained class is not clean and misclassified pixels are in the image, post-processing operation is mandatory in order to increase classification accuracy.

In this research morphological operators are used to improve the image by removing noise and filling gaps. These operators consist of Opening, Closing, Bridge, Clean, Majority and Thicken which are used according to structure of misclassified pixels in the road class binary image.

3.5 C-Means Clustering in Spatial Domain

According to section 3.3, the FCM clustering was done on the grey level values of the pixels in spectral bands of the image. In this step, C-Means clustering is performed on the spatial coordinates of the pixels. So initially, a uniform grid of points is overlaid on the road class binary image and by using C-Means clustering; the location of some predefined nodes is changed. These points are called "Active Nodes". Nodes that their locations remain unchanged are called "Dead Nodes". Dead nodes are simply disregarded for the remainder of the process.

Grid spacing is based on a pre-specified (e.g., operator provided) and differs in different images based on the shape and width of roads in the image.

3.6 Using MST to Extract Road Centerline

In order to extract road centerline, Active Nodes should be connected using MST algorithm. In this application Kruskal algorithm is used to connect Active Nodes and defining road shape. Euclidean distances of all Active Nodes from each other are computed and introduce to the Kruskal algorithm as the weights. Based on what was mentioned in section 2.3, the minimum spanning tree which connects all the Road centerline nodes, are obtained.

This product can be imported into GIS environment in vector format.

3.7 Accuracy Assessment

Accuracy assessment of the proposed road extraction system is performed in two steps: Classification accuracy assessment and Road centreline extraction accuracy assessment.

Classification Accuracy Assessment

In this step, Confusion matrix is made using Ground truth data and classified data and accuracy assessment parameters such as Overall Accuracy (OA), Kappa coefficient, User Accuracy (UA), Producer Accuracy (PA), Commission & Omission Error

(O_e, C_e) are calculated.

These parameters are calculated before and after post-processing of images by means of morphological operators.

Road centreline extraction accuracy assessment

In order to obtaining the differences between manual and automatic extracted road centerlines, distances between these lines are measured in location of Active Nodes. Then road centerline RMS Error is calculated using these measurements in x and y directions.

4. EXPERIMENT WITH IMAGERY

After getting familiar with the proposed semi-automatic road extraction system procedure, the time is ripe to explore the practical results of implementing the system on test images.

Fig. 3 denotes the procedures of semi-automatic road centreline extraction from pan-sharpened IKONOS image of Lavasan city in Iran (1m resolution and 119×170 pixels) in mountainous area. Fig. 3b shows the FCM clustering of input image and resulting road class by defining threshold. It is clear that the details of the clustering are immaterial for the purposes of this investigation but required parameters are presented in the table 1. Fig. 3c shows the result of using morphological operators as post processing operation. What is important is the existence of classification accuracy assessment parameters before and after post-processing which are accessible in table2.

(a)   (b)

(c)   (d)

(e)   (f)
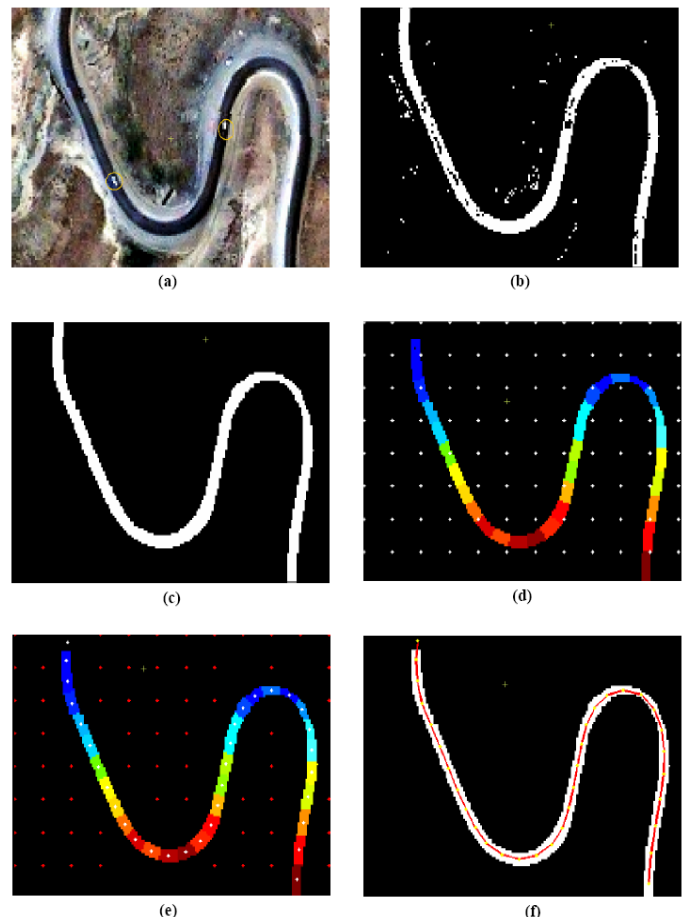
(g)

Figure 3. Proposed system implementation on
pan-sharpened IKONOS image of Lavasan (Test Area 1)

Fig.3d is a 8×12 initialization grid on the road binary image which are translated in active nodes by spatial C-Means clustering in fig. 3e. In fig. 3f these active nodes are connected using MST algorithm (Kruskal algorithm) and road centreline are obtained which are overlaid on the original image in fig. 3g.
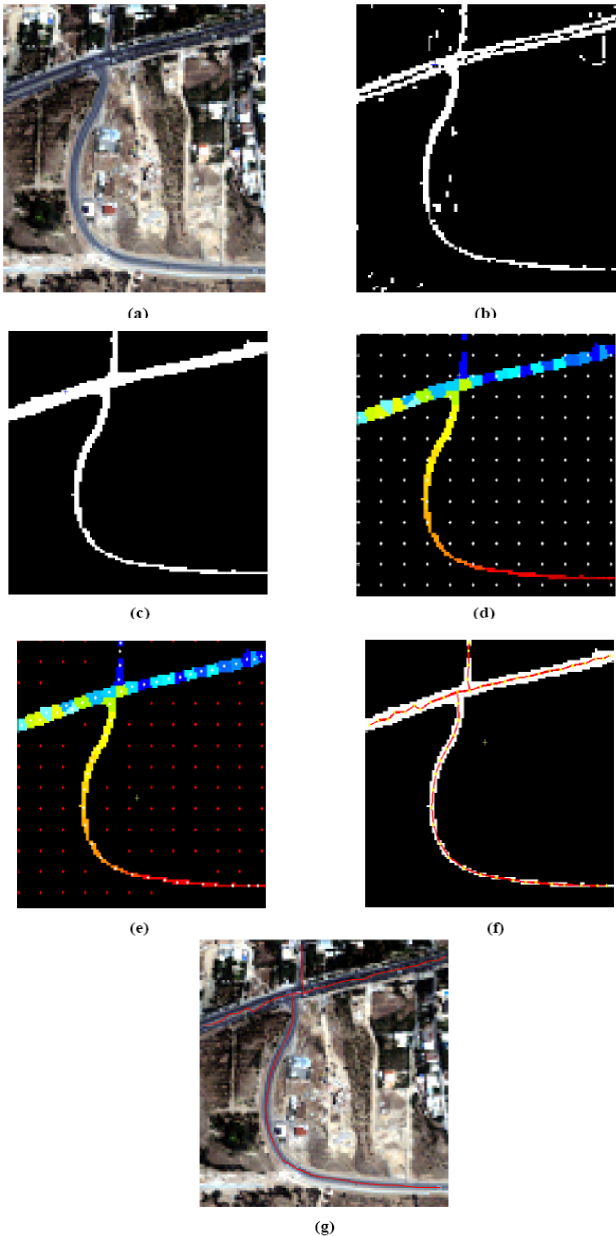
Fig. 4a shows the second test area that is multi-spectral IKONOS image of Lavasan (4m resolution and 115×101 pixels) in semi-urban region. Fig. 4 b-g also shows the predefined procedures of road extraction. Grey level differences of road with its obstacles (for example curbs in this case), leads to causing gaps in the road class binary image.

Kinking effect in fig. 4g is because of densification of grid nodes in order to better presentation of the road shape.

(a)   **(b)**

(c)   **(d)**

(e)   **(f)**

(g)

Figure 4. Proposed system implementation on
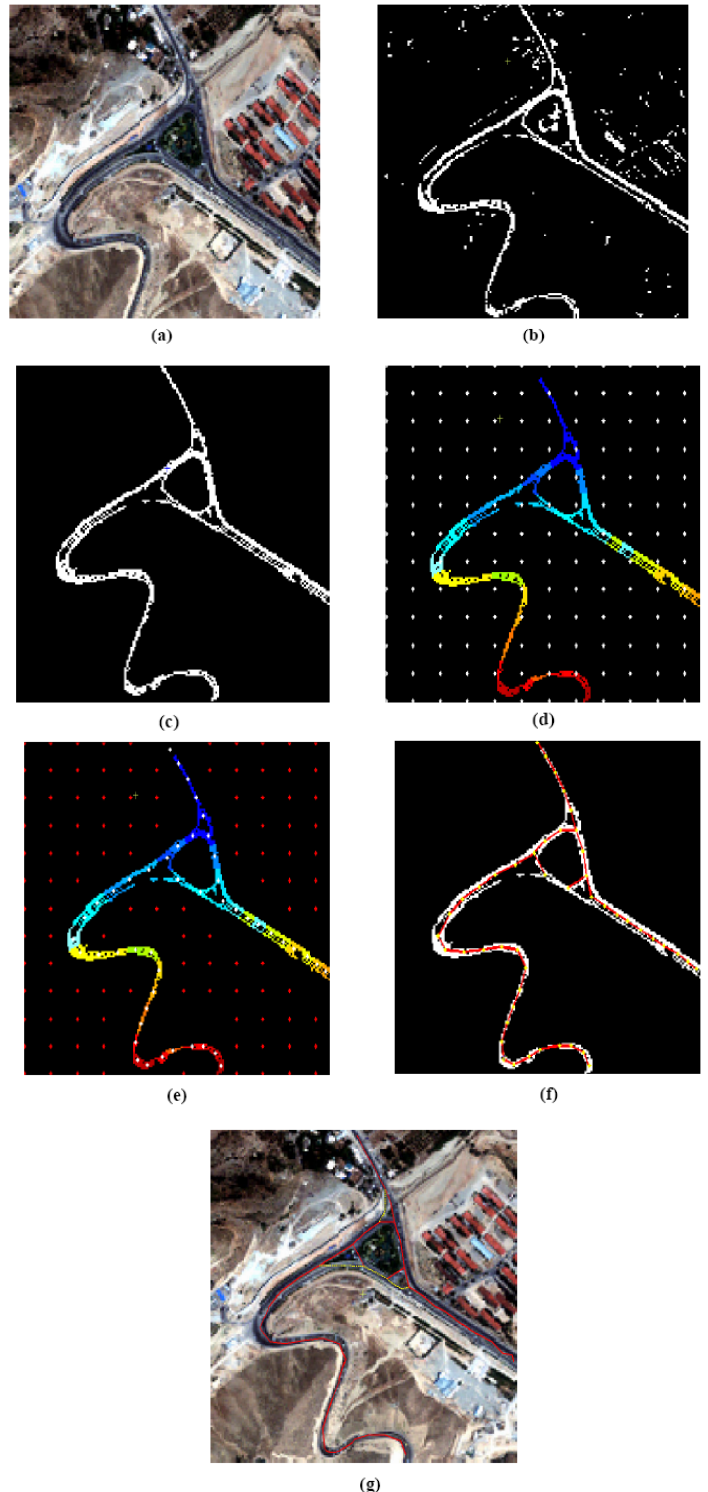MS IKONOS image of Lavasan (Test Area 2)

(g)

Figure 5. Proposed system implementation on
MS IKONOS image of Lavasan (Test Area 3)

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Fig. 5 is another example of multi-spectral IKONOS image of Lavasan (4m resolution and 169×162 pixels) in semi-urban region. In this figure square object that is the place of intersection of three roads, is shown. Again the described procedure of road extraction is implemented on the image. As you see in these figures, the cause of producing gaps on the roads is existence of obstacles such as trees, curbs and cars . these gaps are filled using morphological operators.

The most important problem in fig. 5 is limitation of MST algorithm in closing loops. This restriction causes missed links in extraction of cyclic objects like squares which are shown in fig. 5g by yellow lines. This restriction leads the extraction process to become semi-automatic and supervision of human operator for complement of missed links is compulsory.

to updating road maps. The only drawback of this system is limitation in completely extraction of road center line in place of squares and closed loops. So supervision of human operator for completing missed links and closing the loops is inevitable.

Attaining mean overall accuracy (OA) of 98.2% and Kappa coefficient of 86.26% in classification of image to road and non-road classes, and also mean RMS error of 0.64 pixel in comparing automatic extracted road centerline with manual extracted one, are a good criterion of proposed system success in semi-automatic extraction of road.

Table 1. FCM and C-Means parameters

Fig. No.	Satellite	Bands No.	Spatial Res. (m)	FCM Parameters			Spatial C-Means Parameters		
3	IKONOS (pansharp) (119 ×170)	4	1	K=7	m=2	Euclidean dist.	Grid dim. = 8×12	Active Node no.=33	Dead Node no.=63
4	IKONOS (MS) (115 ×101)	4	4	K=5	m=2	Euclidean dist.	Grid dim. = 13×12	Active Node no.=50	Dead Node no.=106
5	IKONOS (MS) (169 ×162)	4	4	K=8	m=1.5	Euclidean dist.	Grid dim. = 13×12	Active Node no.=71	Dead Node no.=85

Table 2. Accuracy assessment parameters

Fig. No.	Classification Accuracy Assessment before Post-processing (%)						Classification Accuracy Assessment After Post-processing (%)						RMSE pixel
	OA	$Kappa$	UA	PA	C_e	O_e	OA_{final}	$Kappa_{final}$	UA_{final}	PA_{final}	C_post	O_post	
3	97.87	87.13	93.83	83.39	6.17	16.60	98.81	92.83	99.42	88.21	0.58	11.79	0.45
4	94.61	66.21	67.56	70.84	32.43	29.16	97.98	86.45	92.67	82.95	7.33	17.05	0.62
5	96.03	65.59	71.14	64.57	28.86	35.43	97.80	79.51	93.10	71.14	6.90	28.85	0.85

CONCLUSIONS

In this paper a semi-automatic road extraction system based on combination of different feature extraction techniques containing FCM and C-Means clustering technique, morphological functions and graph theory is proposed.
Input images of this system consist of multi-spectral and pan-sharpened IKONOS images of Lavasan city in Iran (with respectively 4 and 1 meters spatial resolution).

The main advantage of this proposed system is achievement of it in extracting different shaped roads such as straight, spiral, junction and square and attaining acceptable precisions in order

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