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Development of GIS-based Road Database Using High-Resolution Satellite Image

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Abstract. The intention of this work is to construct a graph-structured Geographical Information System (GIS) based road database extracted from High-Resolution Satellite (HRS) image. The developed database can be used for implementing the Vehicle Routing and Scheduling Problem (VRSP) in real-life environment. In the first part, the road features were extracted from satellite image using Independent Component Analysis (ICA) technique. Next, the extracted image was filtered to remove different noises. Then merging, splitting and thinning technique were applied for obtaining the single pixel-based road image. Finally, a GIS based database is created using the processed image with the information related to nodes and links of the road network.

Keywords: GIS, Database, Road, Satellite Image, Vehicle Routing.

1. Introduction

The GIS [1], [2] based road network is the basis of many research related to the transportation. One of them is the VRSP, which requires graph-structured (node-link) road database to be implemented in the real world. Traditionally, GIS road map is constructed from scanned paper maps. The digitization of paper map is costly and time consuming. Also to solve a VRSP, we need a current map of the road networks. But sometimes it is very difficult to find a current paper map as it is updated at a certain time interval. These problems insist researchers to construct the road map directly from High-Resolution Satellite (HRS) image.

To date, numerous methods have been reported for the extraction of road features from space imagery [3]-[6]. In the early method of satellite image analysis, the classification was mainly based on spectrum information. But now, information like texture and shape are being used to classify and extract the object more accurately from HRS image [7].

Unfortunately, few methods have been reported so far that can be extended to construct a GIS road database. In this research, we focus on the development of the graph-structured GIS road database directly from HRS image. As a result, a GIS-based road map can be created, displayed and programmed as a map layer in the well-known GIS tools like ArcGIS, MapObjects and MapInfo.

The whole work of this research can be divided into two main parts. In the first part, we extract the road image from the HRS image by using ICA based methods. In the second part, we apply different developed methodologies/techniques for processing the extracted road image. Finally, A GIS-based road database is created to store and manipulate the spatial road data.

2. Background of Vehicle Routing and GIS

The Vehicle Routing and Scheduling Problems (VRSP) have been studied with much interest within the last three to four decades [8]-[11]. The majority of these works focus on the static and deterministic cases of vehicle routing in which all information is known at the time of the planning of the routes. The objective of a VRSP solution is to minimize the transportation costs by better utilization of people and vehicles involved.

In the mid 1960s, vehicle routing used to be done manually due to lack of electronic computing facilities. The output route maps were drawn using paper and pencil method by inexperienced schedulers [12]. During 1970's VRSP were solved using heuristics together with experienced scheduler who had enough knowledge of the condition and constraints of the working area [13], [14]. Later, the development of graphics hardware and software enabled the building of Graphical User Interface (GUI) based VRSP such as FleetManager program [9]. The recent availability of accurate street maps from the GIS data sources, as well as the Global Positioning System (GPS) and image processing technologies, has also stimulated GIS applications for VRSP [15], [16].

3. Methodology

The whole work is divided into several steps. Initially the road image is extracted from HRS image using ICA-based technique. Then extracted image is processed with numerous image processing technique. Finally, a GIS road database is created to store and manipulate the road data. In the following we discuss each technique/method sequentially.

3. 1. Image Segmentation

The input of the process starts with a raw HRS image. Then the image is processed through several steps. The first step is a well-known technique called image segmentation. The aim of image segmentation is to divide the scene into significance regions [17]-[18]. The adjacent similar pixels are grouped together into the same region. Then the interested objects are made isolated from each and other. Therefore the segmented image can be applied to a lot of technical fields such as feature classification, object detection, motion estimation, data compression etc.

We first apply the independent components of RGB space (RGBIC) to classify pixels of the original HRS image. The unsupervised k-means [19] algorithm is used for clustering the spectral features. The predetermined number of object classes is 6 for the experimental HRS image of Fig. 1, and the number is kept the same for the classification by RGB and RGBIC. The results of RGB and RGBIC are shown in Fig. 1(a) and 1(b) respectively, where black pixels are clustered into the same class as the road.

Finally, extracting only the road class from RGBIC image (Fig. 1(b)), we get the output noisy image for road links shown in Fig. 1(c).

(a) RGB (b) RGBIC (c) Road Class

Fig. 1: Pixel-based classification by color features

3.2. The Morphology Filter

Mathematical Morphology, developed in the 1970's by G.Matheron [20] and J.Serra [21], is the analysis of signals in terms of shape. This simply means that morphology works by changing the shape of objects contained within the signal. A morphological filter with closing and opening is applied to a binary image to eliminate the small isolated regions outside the potential left ventricle volume and small cavities inside such volume. The opening filter generally smoothes the contour of an object, breaking narrow isthmus, and eliminating this protrusions. On the other hand, the closing filter also tends to smooth sections of contours but, as opposed to opening it generally fuses narrow breaks and long thin gulfs, eliminates small holes and fills gaps in the contour shown in Fig. 2(a).

3.3. The Length Filter

The satellite image contains many objects such as roads, buildings, trees and so on. Among these the road can be separated mainly considering its length and width. In this section, we describe a technique for calculating the length of a line located in the image.

Suppose, I(x,y) is a binary image in a line denoted as C. Each pixel, P_0 has eight neighbors termed as P_1, P_2,…..,P_8. Then the length of line C can be calculated using the following formula,

C = $\sqrt{(I_x(x,y)-1)^2+(I_y(x,y)-1)^2}$ where obtain I_x and I_y are the X and Y components of image I(x,y) respectively.

Finally, after obtaining the lengths of the image objects, we can set a threshold value. The lengths of the objects are compared with the defined threshold value for extracting the roads.

Fig. 2(b) shows the output of the length filter using the image of Fig. 2(a) as input.

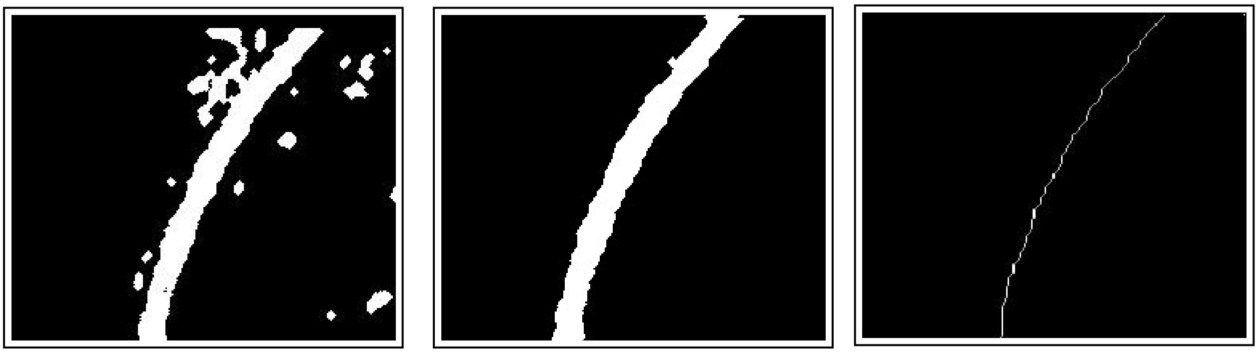
3.4. The Thinning Filter

After applying the morphology and length filters and in order to process the image in GIS programming environment, we need to find the intersection of the links (between two consecutive pixels), which is treated as nodes. Therefore the lines of the image should be changed to 1(one) pixel width. To do so, a thinning filter can be used. In this filter we capture the center pixel by considering its left, right, top and bottom pixels. However, it should be kept in mind about continuity of the line.

After applying thinning process to the image of Fig. 2(b), we get the resultant image shown in Fig. 2(c).

3.5. Steps for Creating GIS Road Database

At the final stage we construct a GIS-based road database by extracting nodes and links from the image. In this section, we discuss several techniques that are applied to extract the road database.



(a) After Morphology Filter (b) After Length Filter (c) After Thinning

Fig.2: The output images of different filters

3.5. 1. Filtering Redundant Pixels

As the extracted road image congested with many unnecessary pixels, it is necessary to remove those redundant pixels to decrease the complexity and execution time of the algorithm. For this purpose, a two-dimensional 9-pixel (3×3) road mask is used. It scans from left to right and from top to bottom. Only one pixel point is considered among these 9 pixels for the next iteration.

3.5. 2. Creating Links

The first step is to create the links between two consecutive image points. We designate these two pixels as Parent-Node (*Pnode*) and Child-Node(*Cnode*) respectively, to describe the sequence of flow direction. The relative physical direction can be a numeric number obtained from the series of integers 1−9 shown in Fig. 3. By placing the *Pnode* at the middle (at cell 5), determine the cell number for the *Cnode*. For example, a link L(100,101,7) means that the link, L starts from node 100 and ends at node 101 with S-E (South-East) direction. Finally, each link is stored in a database file called Links_tab having fields *Pnode*, *Cnode*, *Direction* and *Line_ID*. Among these fields, the *Line_ID* stores the associated line number of a particular link.

3.5. 3. Merging Two Lines

A line can be formed by joining two or more links. The algorithm shown in Fig. 4 uses the Links_tab file's *Pnode* field to find each line. When executing the algorithm, a line joins with another by following two ways:

1. terminal *nodes*,
2. nodes other than terminal *nodes*.

For the first case both the lines are required to merge together whereas one of the lines should be split in the second case. In the following sections, we discuss the procedures for merging and splitting the lines.

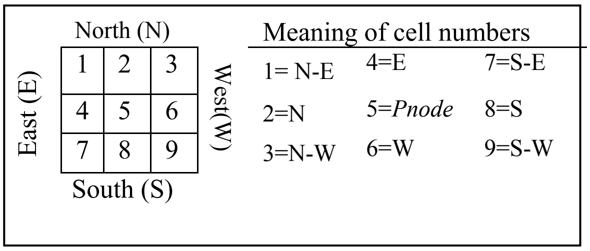


Fig. 3: Numbers indicating the directions of a lin*k*

```
Index Links_tab(Pnode)
Next_Node= Links_tab(Pnode)
Line_Number=1
        Do Loop
          Seek(Next_Node)
           if unvisited record is found then
             Links_tab (Line_ID)=Line_Number
            Next_Node= Links_tab (Cnode)
          else
            exit from the current loop
          end if
```

Fig. 4: Algorithm for creating links

3.5. 4. Creating Links

When two lines meet each other by their terminal nodes then merging is required. There are four ways that a line meets another line (using their terminal nodes).

i. The ending node of line 1 is same as the starting node of line 2, i.e. L_1(E)=L_2(S). In this case, replace the E(*Cnode*) of line 1 with the S(*Pnode*) of line 2, i.e. L_1(E(*Cnode*)) = L_2(S(*Pnode*))

ii. The starting node of line 1 meets ending node of line 2, i.e. L_1(S)=L_2(E). Here, the E(*Cnode*) of line 2 is replaced by the S(*Pnode*) of line 1, i.e. L_2(E(*Cnode*)) = L_1(S(*Pnode*))

iii. Both lines meet using their ending nodes. i.e. L_1(E)=L_2(E). This time, E(*Cnode*) of line 1 is replaced by the E(*Cnode*) of line 2, i.e. L_1(E(*Cnode*)) = L_2(E(*Cnode*)) and swap between *Pnode* and *Cnode* for all links of line 2.

iv. Both lines meet at their starting nodes. i.e. L_1(S)=L_2(S). Then, S(*Pnode*) of line 2 is replaced by the S(*Pnode*) of line 1, i.e. L_2(S(*Pnode*)) = L_1(S(*Pnode*)) and then swap *Pnode* and *Cnode* for all links of line 2.

3.5. 5. Creating GIS Road Database

A database including the information of nodes and links is developed for storing and manipulating the GIS road map data. The database consists of two tables namely as 'Node' and 'Link' shown in Fig. 5 to store the node and link data respectively along with other logistics information. The Fig. 5(a) shows the Node table that contains several spatial and non-spatial information. The same value in *LinkID* field means one link with several nodes. On the other hand table in Fig. 5(b) shows the information related to a link like its terminal nodes, Length, whether crossing node or not and allowable speed. The length is calculated by summing up the lengths between all the consecutive nodes of a link.

Node

node ID	Latitude	Longitude	LinkID	Terminal Node
1	127.7156115243	26.43715213201	1	15470
2	127.7147125825	26.43798903772	1	0
3	127.7141376190	26.43856297361	1	52448
4	127.7186712412	26.43936695576	2	16506
5	127.7185962470	26.43938195328	2	0

(a) Node Table

Link

node1	node2	Line_ID	Length	CNode	Speed
219243	219274	50855	594.524		50
219275	219309	50856	271.674		50
219842	219843	50974	11.094	Yes	20
219838	219841	50973	23.069		20
219835	219837	50972	12.215		20
219812	219843	50986	10.256	Yes	30

(b) Link Table

Fig. 5: Different tables for road database

4. Conclusions

This research helps to create a GIS-based road database directly from HRS image. The road database can be used to display the GIS road map in the display. By using the GIS road map, the company-specific VRSP can be implemented. As the structure of developed database is graph in nature so it would be very easy to implement VRSP in real-life environment. The proposed method is particularly useful when related road-based data are rarely available. The proposed methods can be considered as a fast, accurate and low-cost for creating and updating GIS road map using HRS image.

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