A New Automatic Road Extraction Technique using Gradient Operation and Skeletal Ray Formation

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ABSTRACT
The usage of satellite images and extracting road from the imagery becomes very significant in the services related to road transportation such as maintenance, creation and so on. The literature has numerous works for road extraction but very less contribution is found in dealing with rural areas. In the previous work, ANN-based road extraction technique has been proposed. However to improve the performance of the technique, herewith a new road extraction technique is proposed. The proposed technique extracts the road mainly with the contribution of gradient operation and skeletal ray formation over the subjected satellite imagery. As minor operations, filtering and threshold-based processing is performed. At the end, a coloring is performed followed by a morphological operation to extract the final road from the subjected rural areas. The proposed technique is tested with different satellite images and the results are compared against the previous technique. The comparative analysis show that the proposed technique outperforms rather than the previous technique in terms of standard performance measures such as completeness, correctness and quality.

General Terms
Remote sensing, high resolution satellite images, Road network extraction,

Keywords
Satellite image, road extraction, threshold based processing, gradient, skeletal ray, dominant points, morphological operation.

1. INTRODUCTION
Today satellite and airborne remote sensing systems can provide large volumes of data that are invaluable in monitoring Earth resources and the effects of human activities [11]. The identification of linear features by means of digital image analysis is a generic task in remote sensing [12]. Remote sensing image data typically contain an enormous amount of information [8]. Remote sensing is used to obtain information about a target or an area or a phenomenon through the analysis of certain information obtained by the remote sensor [14].

Images obtained by satellites are useful in many environmental applications such as tracking of earth resources, geographical mapping, prediction of agricultural crops, urban growth, weather, flood and fire control etc [7]. Analysis of high resolution satellite images has been an important research topic for accurate and up-to-date road network information essential for urban planning [5]. One of the major objects that can be extracted from the images is roads that constitute an important layer of vector maps. Road extraction is so far done for highways or wide roads using high-resolution airborne images or low-resolution satellites images [9].

It is easy to identify roads in satellite images manually. But automatically extracting roads from satellite images is a difficult task [6]. Extraction of roads from digital aerial/satellite imagery is not only scientifically challenging but also of major importance for data acquisition and update of geographic information system (GIS), databases or site models and thus can be a big help in car navigation systems or any emergency (rescue) system that needs instant maps [3]. Increasing volumes of high spatial resolution satellite imagery (e.g., Ikonos, QuickBird, OrbView-3, etc.) much of which have never even been viewed has become available now [2]. Digital road information is required for a variety of applications ranging from provision of basic topographic infrastructure over transportation planning, traffic and fleet management and optimization, car navigation systems, location-based services, tourism, to web-based emergency response applications and virtual environments [1].

Road network information is required for a variety of applications. Such information is a necessary input to many decision processes. Manual extraction of road from remote sensing (RS) imagery is mostly time-consuming and costly [2]. Either no digital data is available or often very imprecise and not up to date data is available, i.e., incomplete, or even wrong, for road network in regions that consists of larger parts of desert or dry mountainous areas, e.g., northern Africa. Because of the large areas to be mapped, it is important to use highly automated means as well as cheap and readily available data [4].

Until now, a large number of road extraction approaches have been proposed and published. Road extraction methods have many different forms according to the imagery's spatial resolution. In low-resolution imagery (i.e., ground resolution of more than 2m per pixel), roads correspond to lines, whereas at a resolution of 0.2m-0.5m they can be described as elongated homogeneous areas [10]. Tracking of road edge points in the presence of noise, is the most difficult problem in road extraction because edge points along the road are not necessarily connected in the original edge map [13].

As the significance and complexity in extracting the satellite imagery increases, numerous works have occupied the literature. However, works that deal with rural roads are less. In the previous work, we have proposed an ANN-based road extraction technique, however, the performance of the technique needs to be improved. Hence in this paper, a new automatic road extraction technique is proposed. To understand the prior knowledge about the works that are related with our work, a brief review is made in Section 2. Section 3 details the proposed technique with required mathematical formulations. Section 4 discusses the experimental results and Section 5 concludes the paper.

2. LITERATURE REVIEW

A plenty of works are available in the literature, however a handful of significant works are reviewed as follows.

Jun Zhou *et al*. [15] have proposed a typical way to update map road layers by comparing recent aerial images with existing map data, detecting new roads and adding them as cartographic entities to the road layer. Their method could not be fully automated because computer vision algorithms have not been sufficiently robust and reliable at that time. More importantly, maps have required final checking by a human due to the legal implications of errors. They have introduced a road tracking system based on human-computer interactions (HCI) and Bayesian filtering. Bayesian filters, specifically extending Kalman filters and particle filters have been used in conjunction with human inputs to estimate road axis points and update the tracking algorithms. Experimental results have shown that their approach is efficient and reliable and produces substantial savings over the traditional manual map revision approach. The main contribution of their work has been the proposal of a general and practical system that optimizes the performance of road tracking when both human and computer resources are involved.

Xiangyun Hu *et al.* [16] have presented an automatic road centerline extraction from high-resolution satellite imagery and it has gained considerable interest recently due to the increasing availability of commercial high- resolution satellite images. They have proposed a hierarchical grouping strategy to automatically extract main road centerlines from high-resolution satellite imagery. Hierarchical grouping here has meant that instead of grouping all segments at once, selective segments are grouped gradually, and multiple clues are closely integrated into the procedure. By this means, the computational cost could be reduced significantly. Through the stepwise grouping, the detected fragmented line segments have eventually formed the long main road lines. Their proposed method has been tested and validated using several Ikonos and QuickBird images both in open areas and build-up urban environments. The results have demonstrated its robustness and viability on extracting salient main road centerlines.

Yan Li *et al.* [17] have discussed that aerial and satellite images are rich in information. They are also complex to analyze. For GIS systems, many features have required fast and reliable extraction of roads and intersections. They have studied efficient and reliable automatic extraction algorithms to address some difficult issues that are commonly seen in high resolution aerial and satellite images, yet not well addressed in existing solutions, such as blurring, broken or missing road boundaries, lack of road profiles, heavy shadows, and interference from surrounding objects. Their new scheme has been based on a new method, called reference circle, to properly identify the pixels that belong to the same road and has used this information to recover the whole road network. That feature has been invariable to shape and direction of roads and has tolerated heavy noises and disturbances. Road extraction based on reference circles has been much more noise tolerant and flexible than the previous edge-detection based algorithms. Their scheme has been able to extract roads reliably from images with complex contents and heavy obstructions, such as high resolution aerial/satellite images available from Google maps.

Bong *et al.* [18] have proposed extraction of road regions based on color space elements and edge details of roads. In addition, edge detection method has been applied to further filter out the non-road regions. The extracted road regions have been validated by using a segmentation method. These results have been valuable for building road map and detecting the changes of the existing road database. Their proposed Hybrid Simple Colour Space Segmentation and Edge Detection (Hybrid SCSS-EDGE) algorithm could perform the tasks fully automatically and the user only needs to input a high-resolution satellite image and wait for the result. Moreover, their system could work on complex road network and generate the extraction result in seconds.

Anil *et al*. [19] have discussed that road Extraction from high resolution imagery is of fundamental importance in the context of spatial data capturing and updating for GIS applications. Their research work has been an attempt to automate the process of extracting roads from high resolution imagery. Their work has used statistical region merging for image segmentation and road network has been extracted based on contour partitioning based skeleton pruning method, where the partitions are obtained by Discrete Curve Evolution.

3. METHOD FOR ROAD EXTRACTION FROM SATELLITE IMAGE

Roads are identified from satellite images by performing a sequence of several operations on the extracted image. The processes performed in sequence are briefly explained in the following sections.

Initially we convert the given satellite image SI which may be either a color image or a gray scale image into a binary image SI_b. The value of each pixel is restricted to either 0 or 1 in binary images. In a satellite image containing many small objects, the performance complexity of the image is increased due to the presence of such objects in the SI_b image. So we remove the small objects from the SI_b image by morphologically opening the binary image. This morphological process removes all the connected components lesser than a particular area.

3.1. Pre-Filtering

The filtering process is performed after the removal of small objects from the SI_b image. The filtering process is used for removing certain types of noise from the satellite image. Here we propose a filtering process based on the Gaussian convolution method. Before the filtering process we count the inner area and outer area objects of the SI_b image and get the x and y coordinate values of each object. Then, the array for each object is defined as X and Y using this x and y coordinate values. For example consider that O objects, defined as O = $\{o_1, o_2 \cdots o_N\}$ exist in the SI_b image, where N is related to SI_b image, then the x and y coordinates values of the o_1 objects can be represented as follows,

$$X_1 = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_M \end{bmatrix} \qquad Y_1 = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_M \end{bmatrix}$$

where, M is related to the size of the object.

These X and Y coordinate array values are determined for all the N objects. Therefore each object contains two array formats. The Gaussian convolution filtering method is applied on the x and y coordinates values of each object. After this Gaussian convolution process x and y coordinates values of the objects are given as,

$$X_{1f} = \begin{bmatrix} x_{1f} \\ x_{2f} \\ \vdots \\ x_{Mf} \end{bmatrix} \qquad Y_{1f} = \begin{bmatrix} y_{1f} \\ y_{2f} \\ \vdots \\ y_{Mf} \end{bmatrix}$$

Then, we identify the maximum values from the two arrays X_1, X_{1f} and Y_1, Y_{1f} and perform the division process using these maximum values. Suppose the maximum value of the X_1 and X_{1f} array are x_5 and x_{1f} respectively, then the division process is performed as,

$$x_5 \,/\, x_{1f} = s_{1x}$$

After that, the result of the above division process value s_{1x} is multiplied with the X_{1f} array to obtain a new array result. By employing the same process, the new array result for Y_{1f}, namely D_{1y} is determined

$$D_{1x} = \begin{bmatrix} x_{1f} * s_{1x} \\ x_{2f} * s_{1x} \\ \vdots \\ x_{Mf} * s_{1x} \end{bmatrix} = \begin{bmatrix} x_{1s} \\ x_{2s} \\ \vdots \\ x_{Ms} \end{bmatrix}$$

$$D_{1y} = \begin{bmatrix} y_{1f} * s_{1y} \\ y_{2f} * s_{1y} \\ \vdots \\ y_{Mf} * s_{1y} \end{bmatrix} = \begin{bmatrix} y_{1s} \\ y_{2s} \\ \vdots \\ y_{Ms} \end{bmatrix}$$

The above process is performed for the x and y coordinate array values of all objects and new arrays D_{1x} and D_{1y} are obtained.

3.2. Applying Gradient Operation

The gradient method is used for performing smoothing process in an image and it reduces the noise in the image. In our work we propose a gradient method to perform the smoothing process. We apply a gradient method on the D_{1x}, D_{1y} result of the previous process and the same process is repeated for all objects in the result. In the smoothing process we perform the gradient operation two times. The smoothing gradient operation can be represented using the following formula,

$$d_x = \frac{\partial}{\partial x} \qquad d_y = \frac{\partial}{\partial y}$$

$$dd_x = \frac{\partial^2}{\partial^2 x} \qquad dd_y = \frac{\partial^2}{\partial^2 y}$$

The gradient method is applied on the D_{1x}, D_{1y} arrays, and the resultant arrays are represented as d_x, d_y and once again the gradient method is applied on d_x, d_y and the resultant arrays dd_x, dd_y are obtained. The result of gradient method values are applied in the following formula,

$$c_1 = \left(\frac{d_x * dd_x - dd_y * d_y}{\sqrt{d_x^{\,2} + (d_y^{\,2} * d_x^{\,2}) + d_y^{\,2}}} \right)$$

Here we use d_x, d_y and dd_x, dd_y values and the gradient values are obtained for each object using the above mentioned formula. The result c_1 is an array for any particular object i.e. o_1 and the same result is determined for all objects.

Again the Gaussian convolution filtering process is applied on the resultant array c_1, and the new array c_{1f} is determined.

3.3. Threshold-based processing

The threshold process is performed on each object array to reduce the values from the array. Here individual arrays contained in each object is represented as C = { c_{1f} , c_{2f} ,… c_{Nf} } and the inner area objects and the outer area objects can be clearly identified. First, we compare the outer objects array values with the threshold value (T). We consider only the values that are greater than the threshold value and the remaining values are removed from the array. Next we compare the inner objects array values with the negative threshold value (-T). We obtain the values which are less than the specified negative threshold value and eliminate the remaining values from the array. The threshold process is defined as follows,

Outer area objects ⟶ T_v > pixel values

Inner area objects ⟶ $-T_v$ < pixel values

By this threshold process array values of each object are reduced. The resultant array for all objects can be represented as T= { $T_1, T_2, \cdots T_N$ }

We take first value from T_1 and get object array values corresponding to its position values D_{1x} and D_{1y} are extracted from the arrays. Suppose the value is 5, then the 5th position value is taken from D_{1x} and D_{1y} arrays, the resultant arrays of this process are represented as T_{1x} and T_{1y}. The same process is repeated for all values of the object array T_1 and for all object arrays present in T.

Next we process the c_{1f} array and extract values from c_{1f} array by performing the following steps

(i) If the array c_{1f} contain n values, compare the first and second value, third and second value up to last and first value of the array c_{1f} .

(ii) If the first value is greater than 0, then the second value must be less than 0

(iii) Otherwise, if the first value is less than 0, then the second value must be greater than 0. We extract the second value from the c_{1f} array satisfying the above conditions (ii) or (iii).

(iv) The same process is repeated for all values present in the c_{1f} array and set C, the resultant array is represented as h_1. Then the above steps are repeated for all objects and $H = \{h_1, h_2 \cdots h_N\}$ is obtained.

3.4. Dominant Points and Coordinates Values

The arrays in the H set are compared with the arrays in T i.e. h_1 array is compared with the T_1 array, and same values from the arrays are taken out and stored in array a_1. These values are called as **dominant points,** and the dominant points for all objects are represented as $A = \{a_1, a_2 \cdots a_N\}$. Next, we find the dominant coordinates values. This is performed by taking the dominant point array values from A and filtering the process result array values i.e.D_{1x}, D_{1y} array values. After obtaining one dominant point value from a_1 , the x and y coordinates values of the corresponding position are obtained from the D_{1x} and D_{1y} arrays. The x and y coordinate values are the **dominant coordinate values.**

3.5. Skeletal Rays Formation

The dominant coordinate values are used to draw the tangent lines by connecting coordinate values with the neighboring pixel values. The illustrated tangent lines to all coordinates values are called skeletal rays. Next we mark mid point values for two tangent lines. The mid point values are detected for all object values and all the mid point values are connected. After this process the boundary region areas in an image are identified.

3.6. Coloring

The boundary region values of all pixels are changed using 5 modulo operations and the following coloring conditions are performed on the boundary pixel values.

(i) If the modulo operation result is 1, then all red pixels in a boundary region are converted into white pixels.

(ii) If the modulo operation result is 2, then all red and green pixels in a boundary region are converted into white pixels.

(iii) If the modulo operation result is 3, then all blue pixels in a boundary region are converted into white pixels.

(iv) If the modulo operation result is 4, then all red and blue pixels in a boundary region are converted into white pixels.

(v) If the modulo operation result is 0, then all green and blue pixels in a boundary region are converted into white pixels.

The maximal color pixel values are extracted from the image and the values are put in a newly created mask. Finally morphological operation is performed on the masked pixels.

3.7. Morphological operation

In binary image each pixel is restricted to a value of either 0 or 1. Basically four types of morphological operations are performed in binary image processing. They are erosion, dilation, opening and closing. In an image each pixel in the object is displayed as black, while each pixel in the background is displayed as white. In the proposed system the closing morphological operation is performed. The closing morphological operation is a dilation followed by erosion, and the same structuring element is used for both operations. Closing method is used to join together the circles present in the image by filling the gaps between them and smoothing their outer edges. Erosion can be defined as

$$E = S_m \ominus S_E$$

where, S_E is the structuring element for morphological closing

S_m is the dilated image of S.

These methods are useful for manipulating noisy images where a few pixels have incorrect binary values. For example, an object might be informed to be without any holes or as having a smooth border. The above mentioned operations are performed in satellite images and finally a noise free and precise road image is obtained.

4. RESULT AND DISCUSSION

The proposed classification system was implemented in the working platform of MATLAB (version 7.10). The performance of the proposed system was evaluated using different sample satellite images of rural areas with extracted roads. The below given results are examples of one particular image. The imageries obtained by the proposed system at intermediate stages and also from diverse levels of processing are shown below.

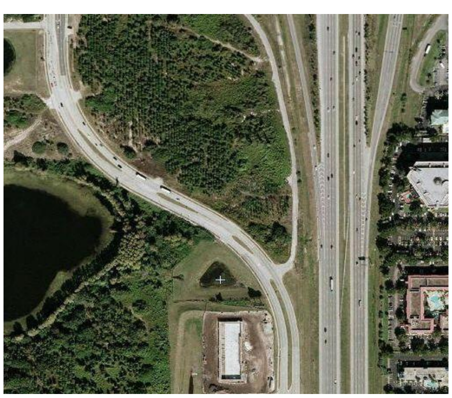


Figure 1: Input satellite road image

Fig. 1 shows the original satellite image that is given as input to the proposed system, after converting it into a binary image and removing the small objects that are present in it. After that the image is given as input to the filtering process for the removal of certain types of noise, and the filtering process results are shown in Fig. 2.

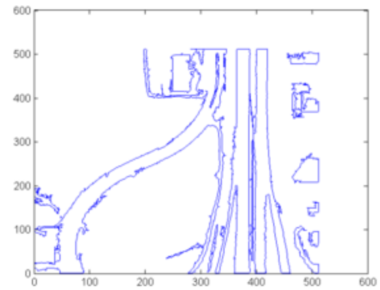


Figure 2: Graph representation of filtering process result

Gradient and threshold process are performed once the filtering process is over. In our proposed system, the threshold values set for T_v and $-T_v$ are 0.02 and -0.02 respectively**.** The values of the verified dominant points and dominant coordinates are plotted in an image and the resultant image is shown in Fig. 3. Fig. 4 shows the result of the formation of the skeletal rays using tangent lines and their mid point values.

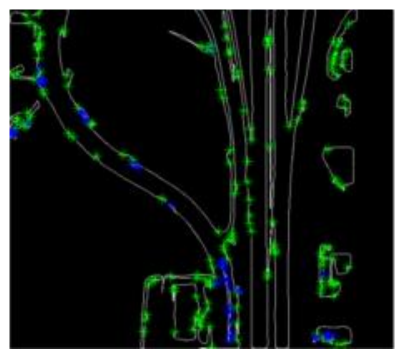


Figure 3:Dominant points and coordinate values result

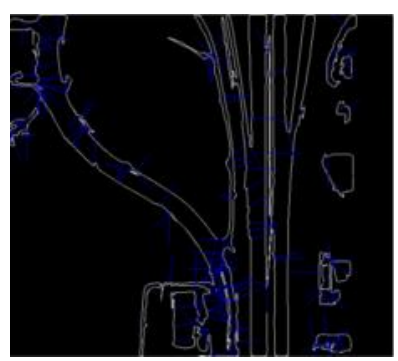


Figure 4: Skeletal rays result

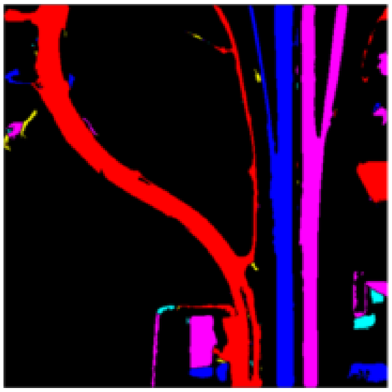


Figure 5: Coloring process result

Figure 6: Maximal color image mask result

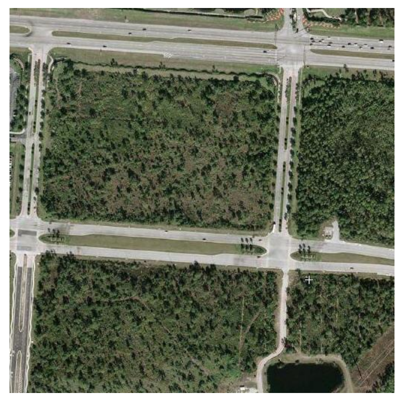
The coloring process results are shown in Fig. 5. From the coloring process, the maximal color pixels are obtained and the pixels are put in a new mask and the results of this process are shows in Fig. 6. Fig. 7 shows images obtained from the morphological closing operation. *Disk* element with parameters $d_{size} = 1$ is utilized for performing the morphological closing operation. The final extracted road image results are shown in Fig. 8.

Figure 7: Closing morphological operation result

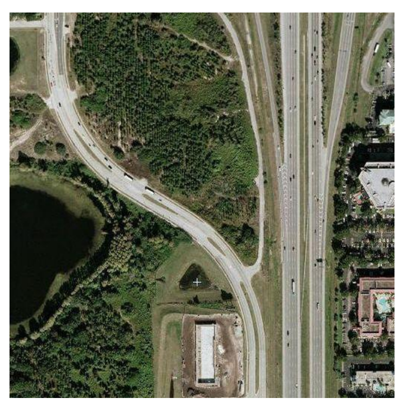
Figure 8: Final road extracted result

4.1 Performance Analysis

Five test images are used to measure the performance of our proposed system. The test images are shown in Fig. 9.



(a)



(b)

(c)

(d)

(e)

Figure 9 (a – e): Test images

Table 1 shows the length of the extracted road and matched and unmatched metrics values obtained for all the five images.

Table 1: Performance Metrics of proposed five images a, b, c, d, and e

Images	Performance Metrics			
	Length of road extracted	Length of road extracted (matched)	Length of reference extracted	Length of road extracted (unmatched)
a	56565	53434	80005	205
b	56436	54979	83158	0
c	71187	55347	85725	2377
D	72070	55519	69581	0
E	78933	49653	60147	1347

Standard quality measures like completeness, correctness and quality are used for assessing the performance of the proposed system. Table 2 gives the standard quality measures [21] such as completeness, correctness and quality obtained for the five image results. The competence of the proposed system in extracting roads from satellite imageries of rural areas is evident from Table 2 and image results.

Table 2: Performance of the proposed system in terms of standard quality measures

Images	Performance Measures (in %)		
	Completeness	Correctness	Quality
A	66.62	94.46	94.12
B	66.11	97.42	97.42
C	64.56	77.75	75.24
d	79.79	77.03	77.03
e	82.55	62.91	61.85

Fig. 10 shows the results of the performance measures completeness, correctness and quality of the test images. From the Fig. 10, it can be visualized that our proposed system performs well in the given test images.

Figure 10: Comparison result of performance measures over the testing images

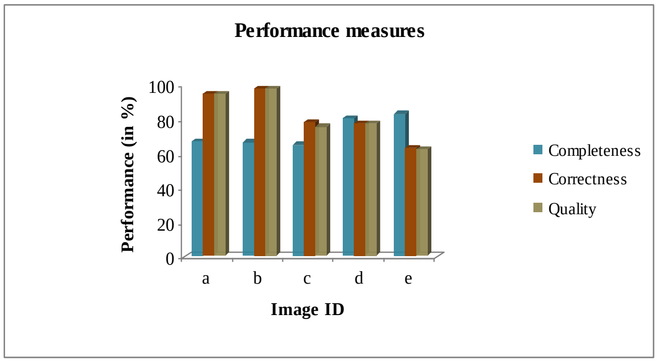
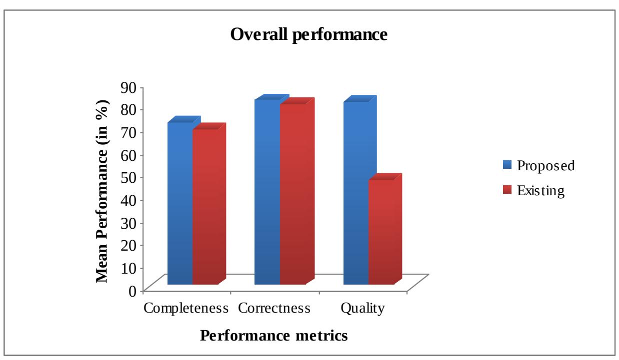


Fig. 11 shows the comparative results between the proposed road extraction technique and our previous road extraction technique [20]. The proposed technique has achieved 72%, 82% and 81% completeness, correctness and quality respectively, whereas the previous work has achieved only 69%, 80% and 46% completeness, correctness and quality respectively. This indicates that the proposed technique relatively shows 2%, 2% and 35% increase in performance over the previous technique. Hence, it can be asserted that the proposed technique is effective over the previous technique especially in extracting the rural roads from satellite imagery.

Figure 11: Comparison result of our proposed system with existing method



5. CONCLUSION

In this paper, we have proposed a road extraction technique for satellite imagery and implemented. The technique has been composed by a gradient process and the formation of skeletal rays over the roads. As minor procedures, filtering and threshold-based processing has been performed and eventually a coloring with morphological operation has been performed to extract the rural roads exactly. The technique has been implemented and compared against our previous technique, which is an ANN based technique. From the comparative results it can be visualized that the proposed technique has achieved a remarkable performance improvement over the conventional technique. The technique outperforms in almost all of the satellite images that are subjected for road extraction. This shows that the proposed technique is effective in extracting the rural roads from the satellite image even rather than the previous technique.

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