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Research Article

Automatic Urban Road Extraction from High Resolution Satellite Data Using Object Based Image Analysis: A Fuzzy Classification Approach

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ABSTRACT

In the present world with a severe economic crisis, time and cost are the most crucial factors for any project. Civil engineering is a field of site execution where activities need an ample of time for its completion due to many factors and any contagious pandemic situation like Covid-19 makes difficult to perform the onsite operations. Hence adopting satellite data for planning purpose where required features can be automatically extracted and analyzed in any GIS software, is significant. This paper aims at the extraction of road features from high-resolution satellite data employing fuzzy classification technique. Worldview-2 satellite data of Gandhi nagar, the capital city of Gujarat, India having 0.5 m panchromatic and 2 m multispectral resolution, is used. Image fusion is carried out by using the bilinear sampling technique of Principal Component Analysis to obtain 0.5 m multiresolution pan-sharpened satellite image. Road feature is extracted by performing multiresolution image segmentation and developing a rule set for classification by adopting the object-based image analysis method. Its accuracy assessment attains the completeness of 71.65%, correctness of 70.33% and quality of 59.98%. This method provides a rapid novel approach for feature extraction with comparatively less data availability as no sun illumination divergence or thematic knowledge or altitude information are used, leading to pandemic suitable remote accessibility and cost-effective approach.

Keywords: Feature extraction; OBIA; Road; Segmentation; Fuzzy classification; eCognition

INTRODUCTION

Computing power and technology applications have seen a rapid advancement over the last decade. The continuously evolving field of remote sensing has proposed many challenges for technology used in various policies and scientific approaches. The stream of digital image processing has improved its feature extraction ability significantly in recent times due to development in different computer technologies [1]. Application of these techniques and technologies in various fields is a challenging task. Several approaches and technologies like crowd sourcing, GIS, remote sensing, surveying and more are used within different attributes. Availability of high-resolution multispectral satellite imagery has made feasible to explore more information by processing and generating enhanced features on the earth surface [2]. Feature extraction is a method of extracting meaningful information which has its applications in traffic surveillance, geographical survey, medical imaging, object recognition and remote sensing [3]. Classification and feature extraction from satellite data are skilled applications of remotely sensed data evoking the need for automation. Civil engineering trade has been actively trying to utilize remotely sensed data [4] that can prove as time-saver techniques like automatic features extraction from available high-resolution satellite data. Urbanization is one of the most distinct anthropogenic land transitions of the present age [5]. Changes in the urban environment enforce updating of the old record, which can help planners to have precise building zones for urban planning, maintenance and development [6]. The remote sensing

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technique of extracting urban features helps in accumulating a large amount of Geographic Information data in a single window. The automatic urban feature extraction has diversified researchers in different applications for overcoming various dynamic urban issues which reduce manual work required for the collection of a large amount of data in a short period, *viz*. generating and modifying Geographic Information System (GIS) data [7,8], urban water bodies, planning emergency evacuation route, defence system and Land Information System (LIS) [9], flood zone and water logging mapping and planning [10] and many more [11].

Automated feature extraction is a kind of grail in the mapping community [12]. The core benefit obtained from automation is time reduction in manual extraction with improved productivity. Considering an increase in complexity of feature extraction due to an enhanced resolution of data, it is a challenging job for any individual solution to be generic. For feature extraction from high-resolution satellite data, pixel-based classification becomes difficult due to diversity in image pixels and small size of pixels as compared to the size of feature such as building, which calls for OBIA [13]. Using different methods from hard classifier (maximum likelihood, thresholding, etc.) to soft classifiers (fuzzy systems, Neural Network, etc) as well as standard Nearest Neighbor algorithm, many studies that have been carried out for different applications proved Object-Based Image Analysis (OBIA) much effective method for complex areas research. Moreover, this method in concert with rule-based classification was introduced to bridge the gap between improved resolution in geo-spatial data and difficulty in recognition of complex features [5]. OBIA utilizes a set of rules hierarchy integrating a huge range of object features like spectral, geometric, shape and texture values. When classifying and measuring homogeneous features from high-resolution data through image analysis, OBIA is superior to pixel-based image analysis [14-18].

Wenxia used of Nearest Neighbor (NN) classification through eCognition software. NN classifier is base on sample objects which are selected manually for the classification process. The accuracy was compared with the traditional method of classification-Maximum Likelihood Classification (MLC). NN classification was 95.47% accurate while MLC was 64.45%. Uzar [19] presented a rule-based approach for classification of data from multi-sensor systems and developed a fuzzy rule-based classification for automatic extraction of building. Verification of extracted data was performed by referencing manually digitized building data for completeness and correctness with 81.71% and 87.64% accuracy. Ziaei (2014) [15] compared three algorithms i.e. Support Vector Machine (SVM), Nearest Neighbor (NN) and Rule-Based system for extraction of buildings and road from WorldView-2 satellite images with object-based classification approach and concluded that Rule-Based approach is satisfactory with the highest accuracy of 92.92% as it works on user-defined rules that are developed in relevant to features to be extracted which depends upon knowledge and experience for the development of ruleset. Aditya [20] attempted to present a conceptual model to overcome the problem of land-use planning by examining the congested cities and spotting out vacant spaces in adjoining areas. The objective this study can be achieved by automatic extraction of building feature from high resolution satellite data using OBIA. Wang [21] research has established a knowledge-based method for extraction of the road using Local Moran's I, for spatial texture used in image segmentation. Based on road knowledge, hypothesis and verification model was used to extract road feature with the accuracy of 94% completeness, 90% correctness and 86% quality. Shobana [22] worked on finding the best possible route for optimizing RMC travel time in Mumbai region of Maharashtra. Using GIS and its several aspects, different data for various routes from RMC plants to construction sites were collected. This research can be enhanced by using extracted roads from satellite data [23-28].

Considering the various methods for extraction of urban features from high-resolution satellite data, this research provides a fuzzy rule set to develop an improved technique for automatic extraction of urban roads using Object-Based Image Analysis (OBIA) in Definiens eCognition software. Furthermore, the road feature from satellite data is digitized and the extracted data is visually interpreted to perform accuracy assessment for evaluation of correctness, completeness and quality of the extracted data. Objectives of this research are performing high-resolution satellite image segmentation, developing rule set for classification of different features, automatic extraction of urban road, visual interpretation, digitization of urban roads and lastly performing accuracy assessment using visually interpreted and digitized data as a reference to calculate completeness, correctness and quality of extracted roads.

STUDY AREA AND DATA SET

The capital city of Gujarat, Gandhinagar is selected as a study area for this research. Gandhinagar is an urban city with a population of around 1,334,445 (2011), consisting of different building rooftop with a variety of building densities, making it a good case for research. Gandhinagar is located on the bank of Sabarmati River to the west, around 545 km (338 miles) from Mumbai (north), which is the financial capital of India and 901 km (560 miles) from Delhi (southwest), which is the political capital of India. Figure 1 shows the geographical location of the study area.

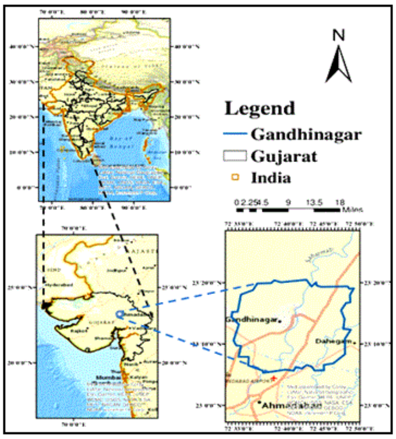
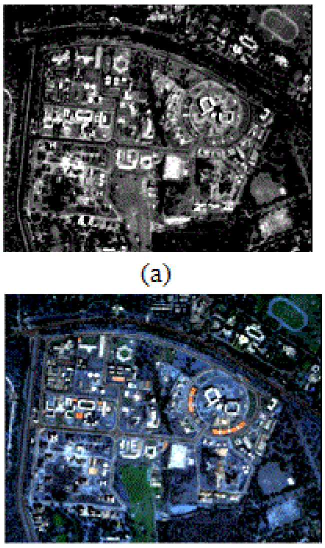


Figure 1: Study Area:Gandhinagar, Capital of Gujarat.



(a)

(b)

Figure 2: WorldView-2 Satellite Data: (a) PAN Image (b) MSS Image.

Gandhinagar data is obtained from WorldView-2 satellite in the form of a multispectral and panchromatic image with a radiometric resolution of 11-bit per pixel. This data is acquired from May 2016 with 0.5 m panchromatic resolution and 2 m multispectral resolution as shown in the Figure 2. In this research, the false color composite (FCC) of the satellite is used for better visualization [23]. Table 1 states the technical specifications of the satellite.

Table 1: Sensor Specifications of WorldView-2 Satellite Imagery.

Band	**Spectral Range**	**Spatial Resolution**
Panchromatic	450-800 nm	0.5 m
Red	630-690 nm	2 m
Green	510-580 nm	2 m
Blue	450-510 nm	2 m
Near Infrared (NIR)	770-895 nm	2 m

RESEARCH METHODOLOGY

This research performs OBIA method and proposes a new rule based classification approach for automatic road extraction shown in Figure 3. This approach lead towards development of a rule set in Definiens eCognition Developer 8.64 on the high resolution data obtained from WorldView-2 satellite. Firstly, the satellite data, having resolution of 0.5 m for panchromatic and 2 m for multispectral, is pan-sharpened in Erdas Imagine 2014 using Bilinear sampling technique of Principal Component Analysis (PCA) to obtain high resolution fused data of 0.5 m. Furthermore, image segmentation is done in Definiens eCognition Developer 8.64 using multiresolution segmentation and after investigation, defining the values for scale ratio, shape and compaction parameters. Moreover, the fuzzy rule based classification is performed by defining classes and applying tested values and thus road feature is extracted from classified data. Besides, the pan-sharpened data is visually interpreted to digitize the road feature which is used for calculating the accuracy assessment of the extracted road feature by means of ArcGIS 10.4.

Image pan-sharpening

Pan-sharpening is the process of integrating two or more images of the same or different resolutions using an approach to acquire a composite image with a high degree of information, also known as image fusion. To combine the advantages of the spatial and spectral resolution of the multispectral and pan image, image fusion technique has included in this analysis. The applied Image fusion has performed by examining various fusion methods like Ehlers, HCS, HPF, Modified HIS, Wavelet and Resolution Merge including PCA (Principal Component Analysis), Multiplicative, Brovey Transform and using different resampling technique by Erdas Imagine [24]. Among them, the output from PCA using bilinear interpolation gave better identification of the objects.

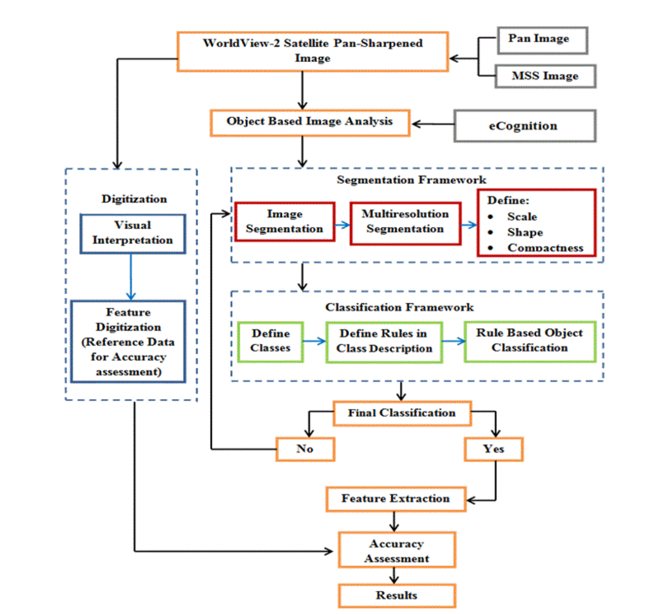


Figure 3: Research Methodology for Automatic Extraction.

OBIA in eCognition

Object-oriented classification in eCognition is a fuzzy logic-based process where various object features such as shape, texture or spectral values are used for classification. Hierarchy of the number of segmentation levels helps to extract image objects which represent image information in different scales simultaneously. This optimized segmentation minimizes the heterogeneity of resulting image objects.

Hofmann et al. [25] Studied the strength of, using fuzzy logic and OBIA together, while it mentioned that by using this logic, desired objects could be classified from satellite data into specific classes based on the fuzzy description. This logic is capable of overcoming the uncertainty and vagueness in spatial entities. The object values decide the degree of membership, where the value of 'if' is equal to zero then membership of the object to a class is zero while if it is 1 then the object is member of that class with complete membership and if it is in between 0 and 1 then the object may or may not be the member of that class or will have partial membership [26,27].

Image segmentation

It is the primary requirement of the OBIA [28], while in this study it is performed using multiresolution segmentation as shown in Figure 4 with red, green, blue and near-infrared bands. For image segmentation, the values of various parameters like weights, size, shape, colour, compactness and smoothness, are selected on trials basis.

These trails are made by changing the values of each parameter to find the best value required for segmentation. Selection of weight values is carried out according to segments to obtain the optimal solution of segmentation that separate the roads of diverse urban area from different nearby objects without thematic information and having the minimum number of bands. The values of final parameters set post trials are 1, 1, 1, 1, 50, 0.5, and 0.4 for red, green, blue, near-infrared, scale, shape, compactness respectively as shown in Table 2.

Figure 4: WorldView-2 Satellite Segmented FCC.

Table 2: Parameter Values for Segmentation in eCognition.

Sr. No.	Parameter	Set Value
1	Red Layer	1
2	Green Layer	1
3	Blue Layer	1
4	Near Infrared Layer	1
5	Scale	50
6	Shape	0.5
7	Compactness	0.4

Image classification

It is the challenging task of developing a fuzzy rule set from relevant object features to map roads [29]. In this research, the knowledge-based classification using the fuzzy rules is performed. Class descriptions in Table 3 show the level of classification containing specific classes of the study area applied through object feature analysis and manual interpretation. These classes are classified using the list of band ratios in Table 4. Vegetation, building, road and shadow are classified by knowledge-based rules, focusing on the road feature. The rule set for classification is stated in Table 5. Finally, the road feature is extracted from the classification data in the vector format.

Digitization

It is the process of converting raster data into vector format, in which a satellite image is used as background and the desired features are traced over it with the help of digitizing tools available in GIS software. In this research, road feature digitization is completed on the satellite image in ArcGIS 10.4.

Digitized road feature shown in Figures 5 and 6 is then compared with the extracted road feature visually and accuracy assessment is performed in ArcGIS 10.4. Figure 5 is manually digitized vector layer of the test site, superimposed on FCC image of satellite data. Some of the fine and sharp road curves present on data make this digitization a bit complex work and may have missed some of the details due to this reason [30].

Figure 5: Digitized Urban Road (a) Vector Layer (b) Vector Layer wit FCC Satellite Data.

Table 3: Class Hierarchy: Urban Road Extraction.

S.no	Class	eCognition View
1	Vegetation	
2	Building	
3	Road	
4	Shadow	

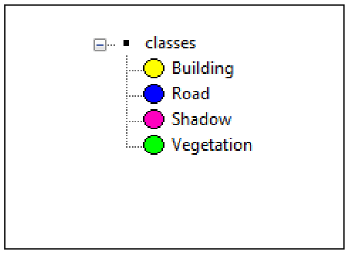


Table 4: Membership Functions/Rule Set in Urban Road Extraction.

S.No.	Band Ratio	Formula
1	NDVI Green	$= \frac{DN_{nir} - DN_g}{DN_{nir} + DN_g}$
2	Water Vegetation Index	$WVI = \frac{DN_r + DN_g}{DN_{nir}}$
3	Intensity 3	$\frac{DN_{nir}+DN_r+DN_g}{3}$

Table 5: List of Band Ratios.

Class	Membership
Building	300<Intensity 3<700
Road	0.2<Density<1.7
	-0.5<NDVI Green<1
Shadow	220<Intensity 3<275
	0<Length<150
Vegetation	-5<WVI<3

Accuracy assessment

Accuracy is the degree of conformity with a true reference. Accuracy assessment of road extraction is performed using an object evaluation analysis. This method works on analyzing the intersection of objects from extracting roads with manually digitized vector layer of roads and further classified into True

Positive (TP), False Positive (FP), False Negative (FN) and error in manual digitization [31]. In this, the objects from extracted roads which overlap with manually digitized roads are true positive (correct extraction). The outputs of extracted roads which do not intersect with manually digitized roads are false positive (wrong detection). The outputs which are manually digitized as roads but are not recognized as roads in extracted data are false-negative (missed detection). For the reduction of errors in manual digitization of roads, the objects under vegetation region and shadow are removed, these are classified as errors. Following are the three widely accepted accuracy assessment measures [32,33] used to evaluate the completeness, correctness and quality of extracted road using reference data.

$$Completness = \frac{AreaofIntersectedReference}{AreaofRefernce} = \frac{TP}{TP+FN}$$

$$Correctness = \frac{Area\ of\ Matched\ Extraction}{Area\ of\ Extraction} = \frac{TP}{TP+FP}$$

$$Quality = \frac{Area\ of\ Matched\ Extraction}{(Area\ of\ Extraction + Area\ of\ Unmatched\ Reference)} = \frac{TP}{TP+FP+FN}$$

RESULTS

From the available satellite data, this research study attempted for the extraction of complex urban roads which dominates in the satellite image. At first, the multispectral satellite data (2 m) was fused with panchromatic data (0.5 m) to improve the resolution of multispectral data to 0.5 m. The fused i.e. pan-sharpened data is shown in Figure 6. Furthermore, classification was performed by applying the fuzzy rule set in Definiens eCognition software for the output in Figure 7.

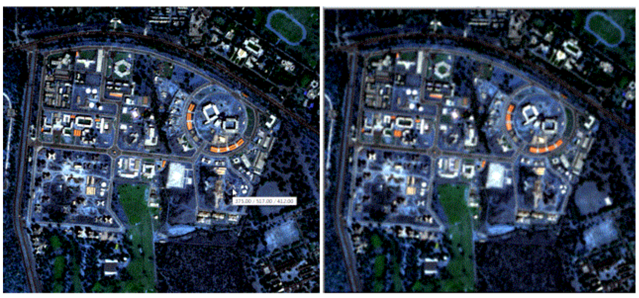


Figure 6: (a) Original Satellite Data (2 m) (b) Pan-sharpened Satellite Data (0.5 m).

The extracted roads colored in blue are shown in Figure 8. Due to intense urbanization as well as high-resolution satellite data, many urban features other than road makes difficult to distinguish the roads. The output shows satisfactory extraction of the required features but at the same time, some features are misclassified or not classified as building and road respectively. To evaluate the accuracy of extracted roads, accuracy assessment was performed to analyze the performance of fuzzy rule-based classification for extraction.

The value of completeness and correctness gives an accuracy measure for classification. For the extraction of road, the completeness value was identified to be 71.66%, correctness was 70.33% and that of quality was 59.98% as shown in Table 6. This accuracy assessment gives the future scope of improvement in this fuzzy rule set for extraction of building in Figure 9.

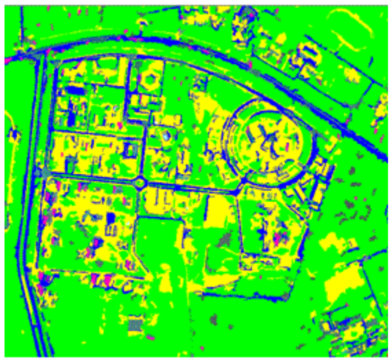


Figure 7: Image Classification focusing road.

Table 6: Accuracy Assessment.

Description	Value
Completeness	71.6%
Correctness	76.3%
Quality	59.9%

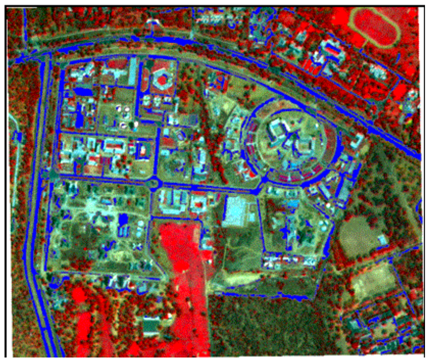


Figure 8: Extracted Urban Road on FCC Image.

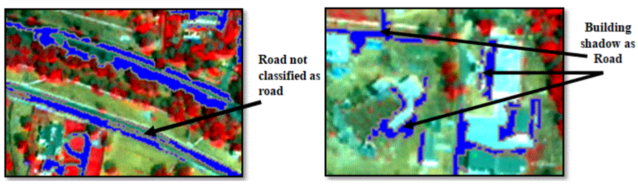


Figure 9: Misclassification of Road.

DISCUSSION

This research signifies an improved method for Urban Feature Extraction with high-resolution Worldview-2 satellite data using a Rule-Based Fuzzy Classification Approach. To achieve this approach, eCognition software was used which grounds on OBIA. For overcoming few issues in object extraction, several visually recognized thresholds were set on spatial and spectral properties. For improving the image quality, pan-sharpening was performed to achieve a 0.5 m pan-sharpened multispectral image. Image segmentation of satellite data was obtained by the multi-resolution segmentation approach, resulting in the formation of different objects. In this study membership functions were used to prepare a fuzzy rule set for extraction of urban road, competitively dominant urban features in the available satellite images, having possible complex curves and angles.

According to the output obtained we can conclude that some surplus area also got classified as a road feature, because of the reflectance property of road and fallow land, which are quite similar. Hence it is the reason why computer misclassified some part of the road as fallow land while some part of the road was not classified as road. Accuracy of the extraction and different urban features that can be extracted from the data gives future scope to the research.

CONCLUSION

This research study has produced a novel method to extract one of the dominant urban features particularly road from high-resolution WorldView-2 satellite data of 0.5 m panchromatic resolution and 2 m multispectral resolution, considering large with complex curves and sharp angles. In any contagious pandemic or disastrous situation occurs where the accessing project site is not possible, feature extraction will play a vital role in collecting data for planning purpose, as it uses remote sensing and GIS technique. This rapid and cost-effective approach requires only a satellite image and no additional data. This approach can reduce the cost involved in feature extraction techniques that usually utilize more time and human efforts involved in developing thematic information or any other data required for road extraction method that uses GIS or any other data.

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