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RESEARCH ARTICLE

Automatic Urban Road Extraction using Airborne Laser Scanning/ Altimetry and High Resolution Satellite Data

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Abstract Automatic road extraction from remotely sensed images has been an active research in urban area during last few decades. But such study becomes difficult in urban environment due to mix of natural and man-made features. This research explores methodology for semiautomatic extraction of urban roads. An integrated approach of airborne laser scanning (ALS) altimetry and high-resolution data has been used to extract road and differentiate them from flyovers. Object oriented fuzzy rule based approach classifies roads from high resolution satellite images. Complete road network is extracted with the combination of ALS and high-resolution data. The results show that an integration of LiDAR data and IKONOS data gives better accuracy for automatic road extraction. The method was applied on urban area of Amsterdam, The Netherlands.

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Background

Roads are an integral part of an urban environment and hence they are an essential input for various applications including car navigation, traffic simulation, tourism, intelligent transportation system, and their regular updation is very necessary for municipal database. In an urban context, a road is defined as “a linear feature, generally rectangular and such a pattern divides the town in to more or less rectangular sectors (Rangwala, 2000) urban road should facilitate communication of human and materials between the various centres of the town". Urban areas are rapidly changing mainly due to human activities in construction, destruction or extension of topographic elements such as buildings and roads (Morgan and Tempfli, 2000), which needs very fast and accurate urban mapping. Changes in urban environment enforce updating of old records, which can help planners to have accurate road network for road planning, maintenance and development. Automatic road extraction from remotely sensed imagery has attracted much attention during last decade. Generally road extraction is based on different kinds of knowledge about roads: geometric, spatial, spectral, radiometry and topological. Road extraction consists of four main steps: road sharpening, road finding, road tracking and road linking (Hu *et al*., 2004; Gruen and Li, 1995). In an urban environment automatic extraction of roads does not provide satisfactory results due to technical hurdles introduced by multilevel construction e.g. high-rise buildings, tunnels and flyovers also have a significant influence on road extraction. Automatically extracted urban roads are affected by shadows of buildings, boundary edges, trees reflection on road edge, etc. therefore, this needs much post editing. Several attempts have been made in remote sensing to extract urban roads (Morgan and Tempfli, 2000; Tao and Yasuoka, 2002; Wang and Trinder, 2000; Zhan *et al*., 2002d). Increase in availability of high-resolution satellite images and ALS data has resulted in addressing the problem of road extraction more efficiently. High-resolution satellite image provides a good basis for reorganization and monitoring of structural changes to map urban details. Higher the resolution of the imagery, greater details related to man made features such as roads, trees, moving objects, etc. could be identified. Even with this detailed information in high-resolution images automatic extraction suffers from the background objects like cars, buildings or trees.

Road extraction in urban areas from satellite imagery has few limitations. There are many challenges to be faced because urban areas are very complex across fine spatial scales. At such High spatial resolutions automatic road extraction does not give desired result, as it leads to misinterpretation of features (man made objects like flyovers, bridges and road above tunnel as ground roads or road junctions). Automatic road extraction in urban areas also suffers with the mixing of road and building edges. Roads are generally constructed parallel to buildings, cycle tracks, sidewalks, which cause road extraction more difficult as they lead mixing of their edges. Certain road features like the bridges, flyovers, culverts, etc. are possibly difficult to distinguish from other topographic features. Automated road extraction in dense urban environment using high resolution imagery suffering from the primary obstacles, which lead to unreliable and incomplete road extraction caused by shadows of buildings, trees and other moving objects (Hu *et al*., 2004). Some existing models (Hinz *et al*., 1999) are sensitive to disturbances like cars, shadows or different hindrances.

An integration of high-resolution satellite data and airborne laser scanning data offer exciting possibilities for automatic and accurate road extraction (Zhan, 2003). Automatic extraction of road using ALS is still one of the challenges in digital photogrammetry and Geo-information sciences (Baltsavias and Zhang, 2004). It is necessary to develop an automatic system, which can extract road information accurately and without any effect of background objects like cars, trees, or buildings.

Literature review

Tao and Yasuoka (2002) proposed a method to combine high-resolution satellite imagery and airborne laser scanning data for generating bare-earth DEM in urban areas. Tree features are calculated through NDVI. They have taken care of road features, which are covered by tree and shadows and used a slope based filtering technique and morphological operators to detect buildings. Due to accuracy in height, ALS data is used. The method of nDEM (normalised digital elevation model) generation is successful but still it needs some refinements. It can be considerably improved by spectral classification with combination of elevation values. Bare earth DEM can be well-generated using ground truth data. The ground truth data is needed to validate the truthfulness of DEM and DTM generation. Another success of feature extraction is reported by Zhan *et al.* (2002d) in the combination of high-resolution satellite imagery and airborne laser scanning for land use classification. Technological aspects like image segmentation, thresholding, triangulation and morphological techniques are used to classify urban features. Different objects are classified using an object-oriented approach. The researchers realised that the urban areas are complicated, so a comprehensive approach is needed and different settings have to be investigated to cope with the different urban areas. They recommended that spatial object based modelling can give better identification of features. Hu *et al.* (2004) have given a method to extract roads automatically using high-resolution satellite in combination with LiDAR data. An interpretation of these technologies is tested on an urban area of Toronto, Canada, which is a highly dense urban area. Using high-resolution satellite imagery, it is difficult to extract roads completely because building boundaries, trees, and shadow obstruct the road patterns. They described road in urban area as grid pattern. LiDAR data were used to extract road strips. An object-oriented approach and morphological operation was used to obtain road strips and parking areas. To extract straight road lane, an iterative Hough transform technique is applied. Finally roads were verified using some rules. The method is successful for extracting grid roads in urban areas with dense buildings and LiDAR data was used to eliminate obstruction of the roads. He recommended that the accuracy of road the road extraction was affected by completeness and correctness, which can be increased using multi-source imageries.

Data used and study area

The urban area chosen for addressing the study problem is Amsterdam in The Netherlands. Amsterdam is bounded by graticule 52° 35' N 4° 9' E (Fig. 1). Altitude of the city is between – 5 and 40 m. It is one of the largest, most beautiful and planned cities in Europe, situated around a dam across Amstel River. The study is conducted in a 9 km^2 area of Amsterdam. The study area is located between geographic extent of 52° 17' 22.74" N to 52° 19' 03.15" N (latitude) and 4° 55' 33.24" E to 4° 57' 51.42" E (longitude). LiDAR and IKONOS images of the study area are shown in Figs. 2(a,b) respectively. The terrain is regular with a flat topography.

Strategy for road extraction

Information content in PAN is higher as a result of its higher spatial resolution whereas MSS enables

Table 1 Data used for the study

S. No	Data	Sensor type	Year of acquisition	Image type/Band	Resolution
1.	High-resolution Satellite Data	IKONOS	2000	Panchromatic	1m
				Multi-spectral	4m
2.	Airborne Laser Data (LiDAR)	TopoSys	1999	True Height Value	1m

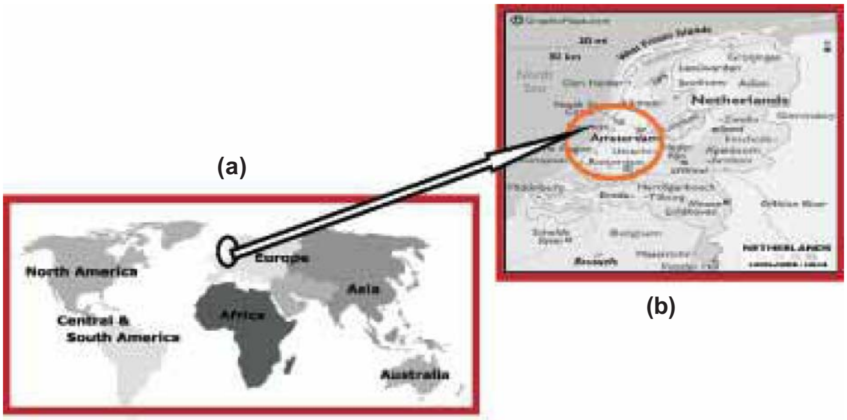


Fig. 1 Location of the study area.

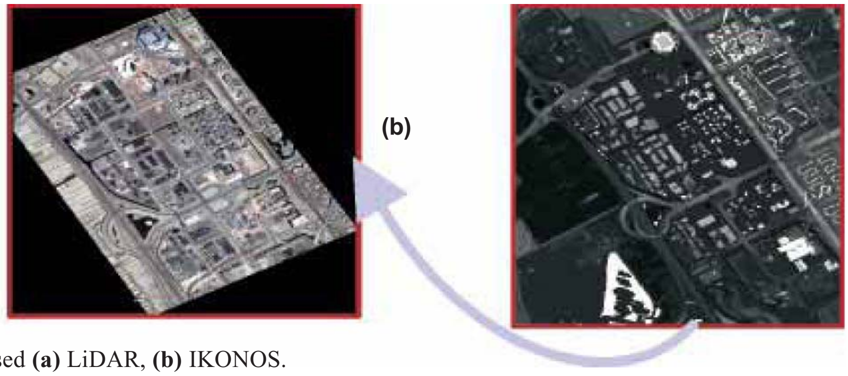


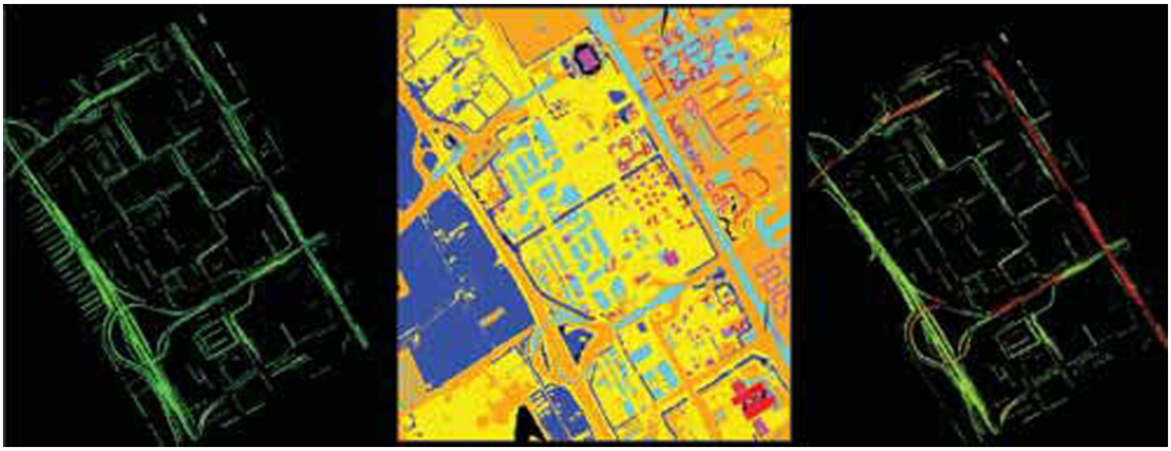
Fig. 2 Data used **(a)** LiDAR, **(b)** IKONOS.

better visualization even with a comparatively lower spatial resolution. Optimally, the best image for micro-level field study (as is the case with the present study) is the one that has the highest information contents of both PAN and MSS. A trade off was inevitable with little or no loss of image information. Image fusion, a widely accepted technique for arriving at such images was utilized. It is defined as "a combination of two or more different images to form a new image by using certain algorithms" (Pohl and Genderen, 1998). Conceptually, Image Fusion is a way of combining the spectral information of a coarse-resolution image with the information at a finer spatial resolution of a second image. The result synergistically combines the best features of each of its components for better visualization. Image fusion based on Principal Components Analysis method was carried out because the spectral properties have to be conserved. Information extraction from high-resolution satellite imagery can be achieved through sub-pixel classifiers and object-oriented techniques (Lee and Warner, 2004; Oruc *et al.,* 2004) Structural stochastic or knowledge-based methods consider spatial characteristics (shape, size and area-perimeter ratio). Knowledge-based methods are needed to increase classification accuracy by separating features like building and roads from other images information and to generate a suitable multi-source/multi classifier for urban regions (Chen *et al.*, 2004) for these methods sequence of processing steps is initially defined followed by setting the parameters and initialization criteria (Granzow, 2001).

Multi-resolution segmentation allows the segmentation of an image into a network of homogeneous image regions at any chosen resolution. These image object primitives represent image information in an abstracted form serving as building blocks and information carriers for subsequent classification, beyond purely spectral information, image objects contain a lot of additional attributes which can be used for classification: shape, texture and – operating over the network – a whole set of relational/contextual information. The basic element of an object-oriented approach is the image object or segment is not single pixel.

Knowledge Base provides an intelligent and integrated knowledge solution that promotes easy image information extraction. Generally knowledge base summarizes all the algorithms, definitions and parameters necessary to process information to a certain purpose. It contains the specific domain knowledge to solve the problem. Various rules were applied for classifying road segments. Spectral, shape, textural and contextual properties of the objects were utilized for formulating rules for road extraction (Fig. 3a). Lidar Data was processed to generate Digital surface model. Lidar point cloud was filtered to classify ground and non ground points (Fig. 3b). Height threshold was applied to extracted roads using lidar point cloud to separate out ground road and elevated roads (Fig. 3c).

To evaluate the success of the results of road extraction, the extracted roads were subjected to an accuracy assessment. Accuracy is the degree of conformity with a true reference. Wiedemann *et al.* (1998) have suggested certain algorithms to check the accuracy. The quality of each road can be evaluated by contemplating the completeness and correctness of the extracted road network. The contiguity of the two road networks (reference and extracted road) may lack in coherence, hence the accuracy cannot be judged directly. Buffer method can be used for accuracy assessment of automatically extracted data with respect to reference data. This method works depending on buffer generated with threshold distance around the road network. For assessment of completeness, a buffer of constant predefined width is constructed around the reference road data. The parts of the extracted road data lying with in the buffer are considered as matched extraction and outside the buffer as non-road or unmatched extraction. The matched extracted



(a) (b) (c)

Fig. 3 **(a)** Roads extracted with object oriented rule based classification, **(b)** Filtered Lidar data, **(c)** Ground and elevated roads.

road is denoted as true positive whereas unmatched extraction as false positive. For correctness, a buffer is built around the extracted road network with using predefined threshold value and the parts of reference data lying in the buffer are considered as matched (Fig. 4).

$$\textbf{\textit{Quality}} = \frac{\text{(length of matched extraction)}}{\text{(length of extraction + length of unmatched reference)}}$$

Quality $\in$ {0; 1}.

The optimum value for completeness, correctness and quality is 1.

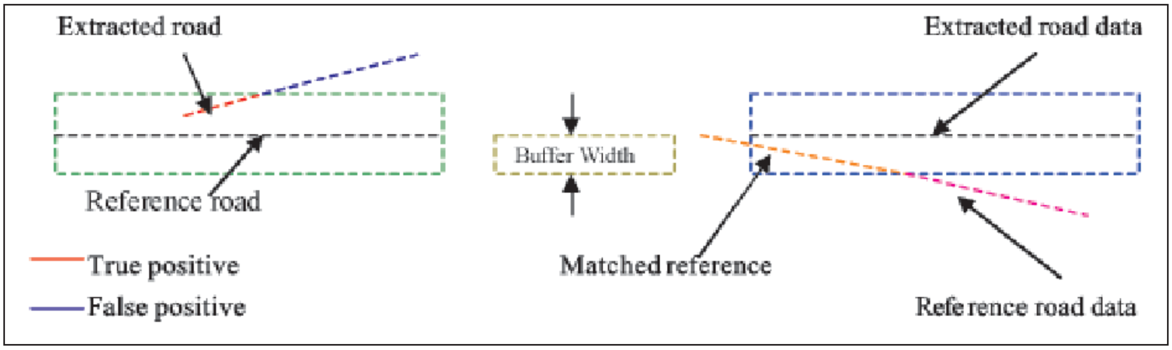


Fig. 4 Accuracy assessment strategy.

The parameters are defined and calculated using these formulas:

"***Completeness*** is the ratio of the correctly extracted records to the total no of relevant records within the ground truth data", and can be calculated as-

$$\textbf{\textit{Completeness}} = \frac{\text{length of matched reference}}{\text{length of reference}}$$

Completeness $\in$ {0; 1}.

"***Correctness*** is the ratio of the number of relevant records extracted to the total number of the relevant and irrelevant record retrieval", and can be calculated as-

$$\textbf{\textit{Correctness}} = \frac{\text{length of matched extraction}}{\text{length of extraction}}$$

Correctness $\in$ {0; 1}.

"***Quality*** is the measure of final result combining completeness and correctness", and can be calculated as-

Results and analysis

In the case of road, completeness of 76.26% and correctness of 50.78% was achieved. The overall accuracy observed for the road extraction was 43.85%. With this result it was evaluated that more than 3/4 part of the whole road network was completely extracted with the correctness of nearly half of the total road network (Fig. 5).

While in the case of elevated road/flyover, a completeness of 88.61% and correctness of 85.71% achieved. The overall accuracy of the elevated road extraction was examined as 77.21%. The output result shows that most of the part of elevated road network was completely and correctly extracted to the total road network. The output results of roads and elevated roads are compared in Fig. 6. In the study area, urban scene was highly complex and contained high-rise buildings, open-grounds, medium-rise buildings, etc. which mainly affected the accuracy of road extraction. Figure 5 indicates some of them.

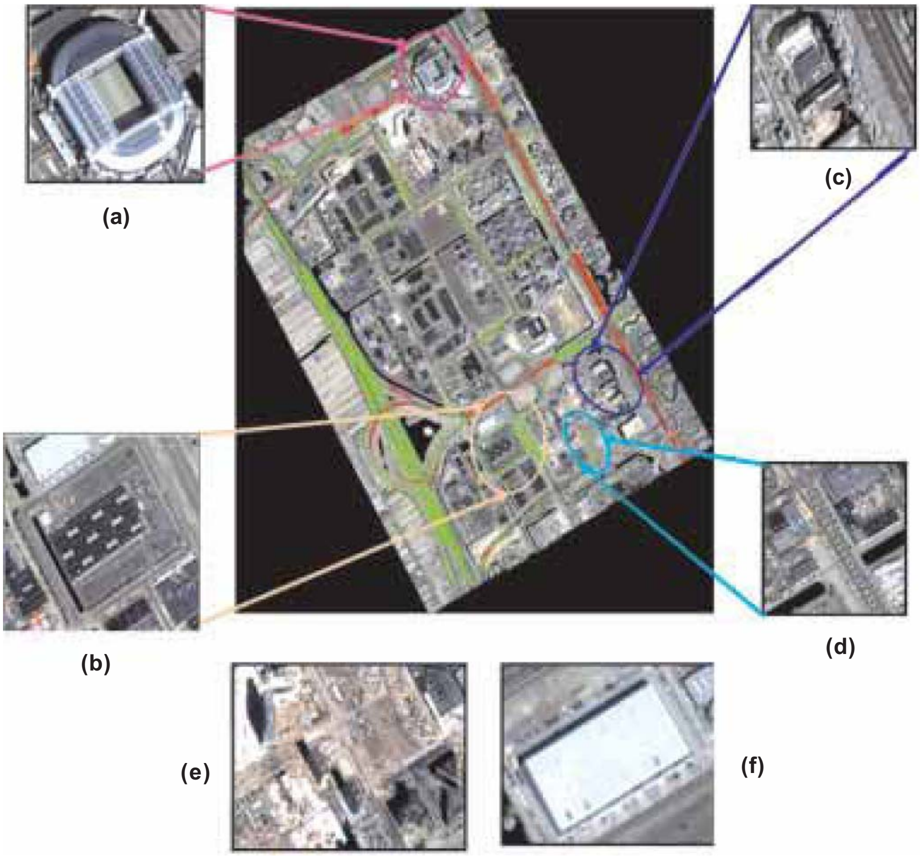


Fig. 5 Occulations in urban road extraction.

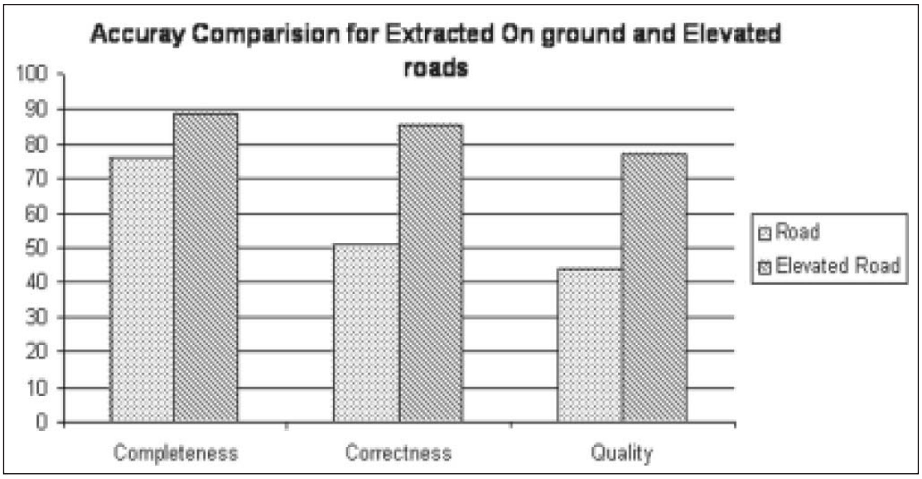


Fig. 6 Comparision of extracted ground and elevated roads.

- In Fig. 5(a) and (f), we can see that roads, stadium top and building top have similar spectral reflectance.
- Figure 5(b), (c) and (d), these are some of the snap shots of roads, which are surrounded by trees. The roads can be better reconstructed in these places, if trees can be extracted out. NDVI can help in extraction of trees. Once the trees are extracted out, the better road extraction can be expected.
- Figure 5(e) shows, shadows of high-rise buildings are falling on the road. Classification using fuzzy approach normally labels high membership value to each object with respect to others. The larger difference between the highest and lowest membership value sometimes extract other object also.

Conclusion

Roads are important features in urban context. Urban planners need methodologies for fast road data acquisition, which can be done through satellite remote sensing techniques and airborne laser data. Automatic extraction of road network information using remotely sensed data suffers with some problems, especially in urban areas due to spectral complexity in the scene. To overcome such problems an integrated approach of high-resolution satellite data and LiDAR data have been studied, which can extract urban road efficiently with the help of commercially available softwares. Here high-resolution data have been used to extract ground roads. The combination of LiDAR and IKONOS data was further used to provide a smooth road network, so as to eliminate edges other than the roads. A methodology for automatically extracting and recognizing roads has been attempted. However, software limitation was one of the challenges of the research.

The integrated approach of high-resolution satellite data and LiDAR has shown their best results using commercially available softwares. But still there are further scope for research, which can result in better accuracy of extraction.

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