AMSE JOURNALS –2015-Series: Advances B; Vol. 58; N° 1; pp 53-66
Submitted Dec. 2014; Revised May 30, 2015; Accepted June 15, 2015

Towards Robust Analysis of Satellite Images of Algeria Application to Road Network and its Nodes Extraction

Z. Nougrara

Department of Mathematics, Faculty of Mathematics and Computer Science, University of Science and Technology of Oran (Mohamed Boudiaf University) Oran, Algeria
(nzrecherche@yahoo.fr)

Abstract

Actualization of cartographic data using imagery is an important application in the earth sciences. Extraction of map objects such roads from satellite imagery are an important task in many civilian and military applications. Particularly, extraction of these objects from digital imagery is of major practical importance for data acquisition and update of geographic information systems GIS database. So, the integration of automatic objet extraction from imagery and GIS for the update of geodata becomes more and more important. In this article, we present a study which its main objective is to solve the problem of the automatic update a roadmap. This study is thus applied for that the geographical representation of the images is as near as possible to the reality. It concerns a proposed approach for semi-automated extraction of road networks with its nodes (intersections points between each two roads) by optimizing the developed methodology for this problem of extraction from satellite imagery in our previous works (Nougrara and al., 2011 and 2012). It is founded on the information theory and the mathematical morphology; the information theory and the mathematical morphology are combined together to extract and link the road segments to form a road network and its nodes. We therefore have to define objects as sets of pixels and to study the shape of these objects and the relations that exist between them. In this approach, geometric and radiometric features of roads are integrated by a cost function and a set of selected points of a crossing road. Tests of this approach are conducted on satellite imagery. The results show that the proposed method can successfully extract objects (roads, road network and nodes) from the satellite images and optimize the time when comparing to some existing methods in this field.

Key words

Road, road network, node, satellite image.

1. Introduction

Cartographic object extraction from digital imagery is a fundamental operation for GIS update. However the complete automation of extraction processes is still an unsolved problem. In fact, many works on this topic have been presented in the literature. But the manual intervention of an operator in extracting, defining and validating cartographic objects for GIS update is still needed. In fact, this problem of the complete automation of extraction process is bigger that many researchers have opted for semi-automatic extraction methods.

In this paper, we propose a novel method for semi-automatic extraction and GIS update which is based on (Nougrara and al., 2011). The remainder of this paper is organized as follows: in section 2, we present an overview of the literature. In section 3, we describe the proposed method in detail. In section 4, results and comparisons are presented on satellite images of Algeria. Finally, conclusions are given and possible directions for future research indicated in section 5.

2. Literature overview

Traditionally, mapping a road is implemented manually, which is tedious, time-consuming and expensive (Lin and al., 2009). An automated or semi-automated method for acquisition and update of road data using computer vision algorithms is greatly needed to increase efficiency.

Extraction of features from satellite/aerial imagery is an important task in many applications that rely on geographic information systems GIS (Chaudhuri and al., 2012). Recognition of roads is critical since they form an important GIS layer in significant civilian and military applications. In particular, extracting road networks from digital images is important for different applications, such as thematic cartography, timely update of urban GIS, disaster assessment and military reconnaissance (Li and al., 2015).

Automated road network extraction from remotely sensed imagery can be used to simplify the creation and updating of road databases and make the process more efficient. However, fully automated algorithms to recognize them for applications where accuracy is critical are not currently available (Chaudhuri and al., 2012).

Models for the automatic and semi-automatic extraction of roads and road network by remotely sensed imagery can be found in the literature. In fact, many strategies, methodologies and algorithms for road network extraction have been presented since 1970s, which have achieved varying degrees of success. According to the level of automation, the techniques for road extraction with the aid of computer vision can be coarsely classified into automatic and semi-automatic approaches (Lin and al., 2009).

J. B. Mena (Mena, 2003) presented a bibliography of nearly 250 references related to this topic, and a novel classification of road extraction methods according to their criteria is included; multiples methods, works and proposals have been considered, including a comment in many of them. Also, (Mena and al., 2005) presented a system for automatic road extraction; this system includes the geometrical and topological definition of the graphics elements (rural and semi-urban areas) of satellite images. Another system was proposed by (Jin and al., 2005); this system incorporates multiple automated road detectors and a road tracker; the road detectors are chosen differently for different environments. Also, (Guan and al., 2014) developed an automated method for extraction of road information from mobile laser scanning data. For semi-automatic approaches, we can present some techniques: a semi-automatic system was proposed by (Lin and al., 2009) for road tracking; it concerns a combination of multiple algorithms for extracting road networks from multiple source remotely sensed imagery. Another approach (Chaudhuri and al., 2012) introduced semi-automated road detection; it exploits both the spectral and special properties of roads using a multi-step approach.

With the development of high way and rural roads, road networks have recently become more and more complex, and many new roads are constructed every day (Yang and al., 2014). So, the update of geodata becomes more and more important; in many countries large geodatabases were built up in the last decade which has to be kept up to date and the progress in automatic object extraction will lead to practical application.

Many methodologies for road network extraction and its use for several applications, particularly for updating geographic information systems GIS have been presented by different works, such as the work (Hu and al., 2007) which presented a method for road network extraction and cited some applications of this method (automated correction, updating for geographic information systems GIS, registration with multi temporal images for change detection, automatically aligning the spatial datasets, etc.). Also, the study of (Li, 2010) which introduced utilities of processing of multi-temporal images and change detection; in fact, change detection is very important for economic construction and national defense; it is a core problem in resource and environmental monitoring, disaster monitoring, land cover, change, city expansion, geographic information update and military defense. Another work very recent was proposed by (Li and al., 2015) which developed a method for extracting man-made objects from remote sensing images, and given some applications of this work such as road networks, building roofs, airport, runways, thematic cartography, timely update of urban GIS, disaster assessment, and military reconnaissance. Finally, other works have been considered related to GIS applications, such as the works of (Mandal and al., 2004) and (Aït Ouahman and al., 2008).

After reviewing the existing works on roads and road network extraction, it was realized that a combination of few algorithms (in our case two principles are used: information theory and mathematical morphology) is more robust for extracting roads and its road network and also its nodes (points of intersections between each pair of roads) from satellite images than the multiple or individual algorithms.

3. Proposed methodology

The core idea of this proposed methodology is to optimize our previous algorithms (Nougrara and al., 2011); to obtain results in the fast and robust way taking into account the time of execution of treatments concerning extraction of a road network with its nodes from satellite image.

To extract a road network with its nodes, our idea (Nougrara and al., 2011) is based on the criterion that a road network is defined by a set of roads crossed two to two in a node (a node makes it possible to cut a road in a set of segments of roads and to pass from a road to another road); thus we have used the mathematical morphology for solve this problem of extraction (the mathematical morphology is to represent the object of study by one or more sets in suitable areas for analysis, using set-transformations like: union, intersection, dilatation, erosion, etc.).

To recognize entities of roads, it is difficult to extract them by their radiometric only because roads do not have the same spectral response according to their state, surface, etc. So, it is to extract these entities by the textural component elements and to reconstruct linear structures by connecting models taking into account the shapes of these objects. Thus, we have applied for this problem of extraction, the information theory. Our idea (Nougrara and al., 2011) is based on the criterion that a road can be defined like a set of arcs; each arc is a set of lines. So, we want to reconstitute the shape of a curved object after its digitalization. The best shape of a road is that minimizes the variance calculated in the possible directions of propagation, that maximizes the covered distance and that is most rectilinear. Thus we must detect homogeneous elements then linear components of the road.

Calculating the homogeneity of elements road requires four masks of directions: 0, $\pi/4$, $\pi/2$ and $3\pi/4$. The figure 1 represents these masks by a representation in the form of the coordinates:

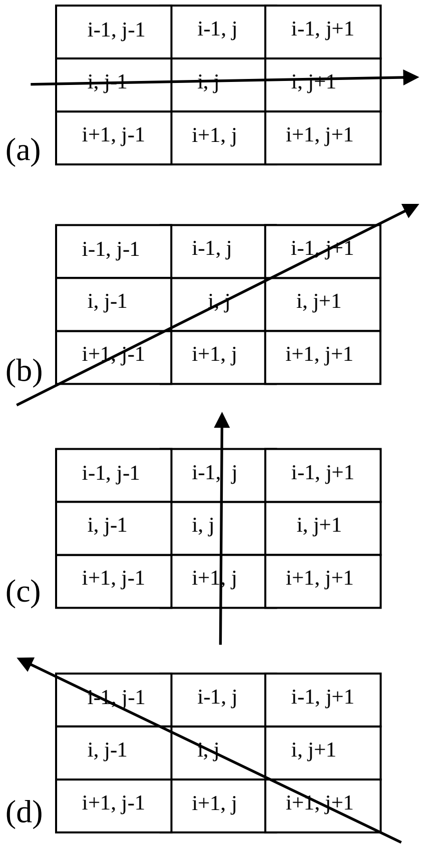


Fig.1. Neighborhood example for different masks of directions:

(a) 0, (b) $\pi/4$, (c) $\pi/2$ and (d) $3\pi/4$

The linearity of components of road needs a partition of the image of homogeneous elements in windows of size fxf pixels. The figure 2 shows an example of this partition:

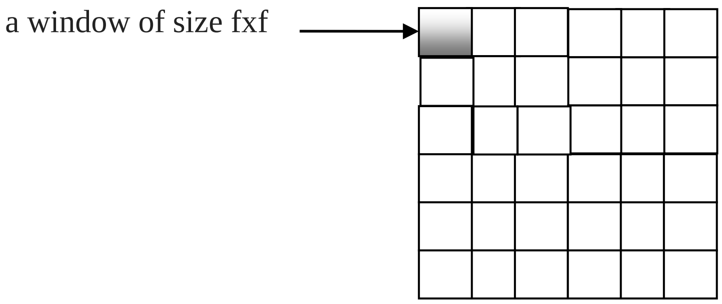


Fig.2. Decomposition of the image of homogeneous elements in windows of size fxf

This is to calculate the two vectors X (binary vector for the exact location of a segment of road in each pair of windows) and Y (random vector of likelihood for the presence of a segment of road in this pair of windows). The calculation makes finding a path representing a road on the decomposed image. The figure 3 gives two examples on values of vectors X and Y in a pair of windows:

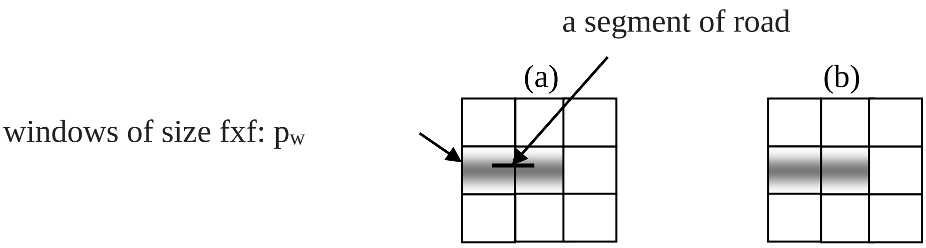


Fig.3. Example of a pair of windows: (a) this pair contains a segment of a road, (b) this pair does not contain a segment of a road

For these two cases, the values of X and Y are: in case (a) $X_{pw} = 1$ and $Y_{pw} \approx 1$; in case (b) $X_{pw} = 0$ and $Y_{pw} \approx 0$.

For the choice of the best road, this is to calculate the vector x (vector composed by a set of points where x_i belongs to the segment road located by the vector X). The calculation of the vector x permits of find an exact detection of road on original image. The figure 4 represents an example of a road composed by the vector x:

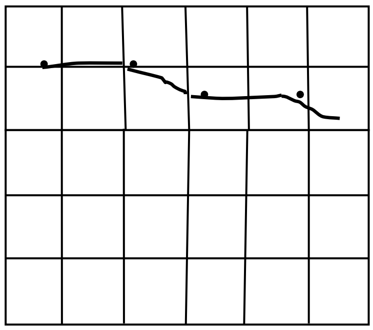


Fig.4. Example of work procedure of extraction of a road

Our new algorithm of extraction of a road network and its nodes is ameliorated by an iterative principle for this extraction. Our strategy consists to alter between extraction and union for an optimization objective. So, the extraction of three objects: road, road network, and nodes has been applied in parallel.

3.1 Algorithm of extraction

Algorithm:

(1)- To fix the number of roads which composed the road network which will be extracted.

(2)- Applying the algorithm of extraction of a road (Nougrara and al., 2011) twice: the result is two roads.

(3)- Application of the algorithm of the morphology operator 'union' (Nougrara and al., 2011) for having the first road network composed by the two extracted roads.

(4)- Application of the algorithm of the morphology operator 'intersection' (Nougrara and al., 2011) for having the first node if the two extracted roads have this same node.

(5)- To repeat the three algorithms for extracting a road then extracting a road network and finally extracting a node until the fixed number of roads is reached. The result is two images: the first one comprises the extracted road network and the second one contains all nodes of this extracted road network.

(6)- Application of the algorithm of the morphology operator 'union' for having the new image of the extracted road network with its nodes.

4. Experimental results and discussions

In this section, some experiments which test the proposed method are described. The proposed method is also compared with some other methods in the literature to show its advantages and disadvantages.

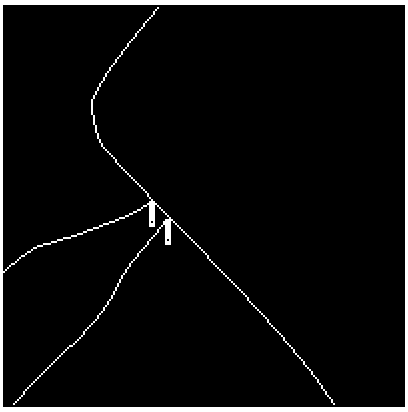
4.1 Experiments

Data sets:

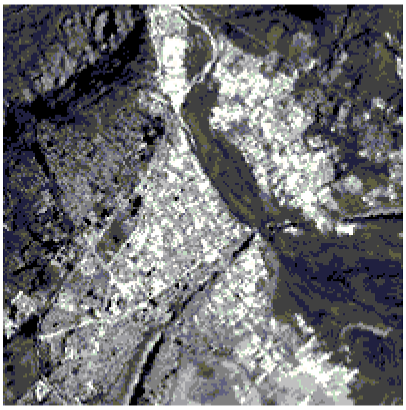
As examples, the figures 5 and 6 show original and subsets of satellite image over Laghouat area of Algeria country (these typical images are selected to test the proposed method; they contain different types of roads) and their extracted results.

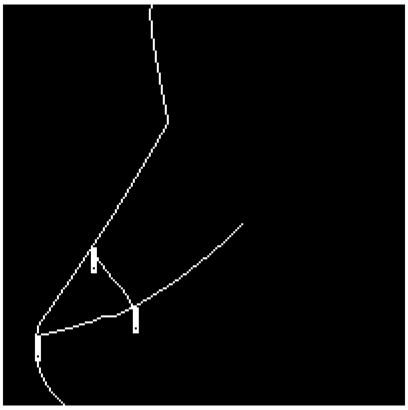
Fig.5. An original 280x419 satellite image of Laghouat area of Algeria country

(a) (b)

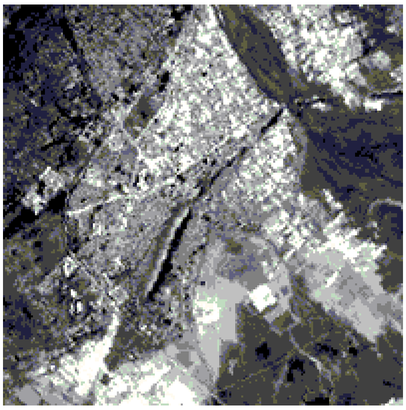


(a) (b)





(a) (b)



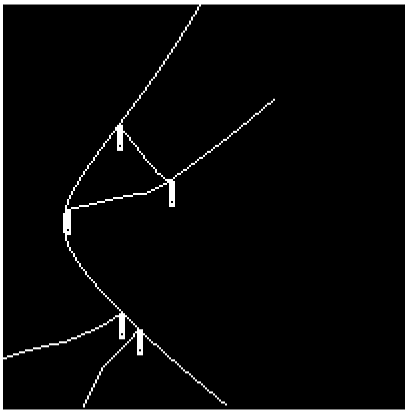


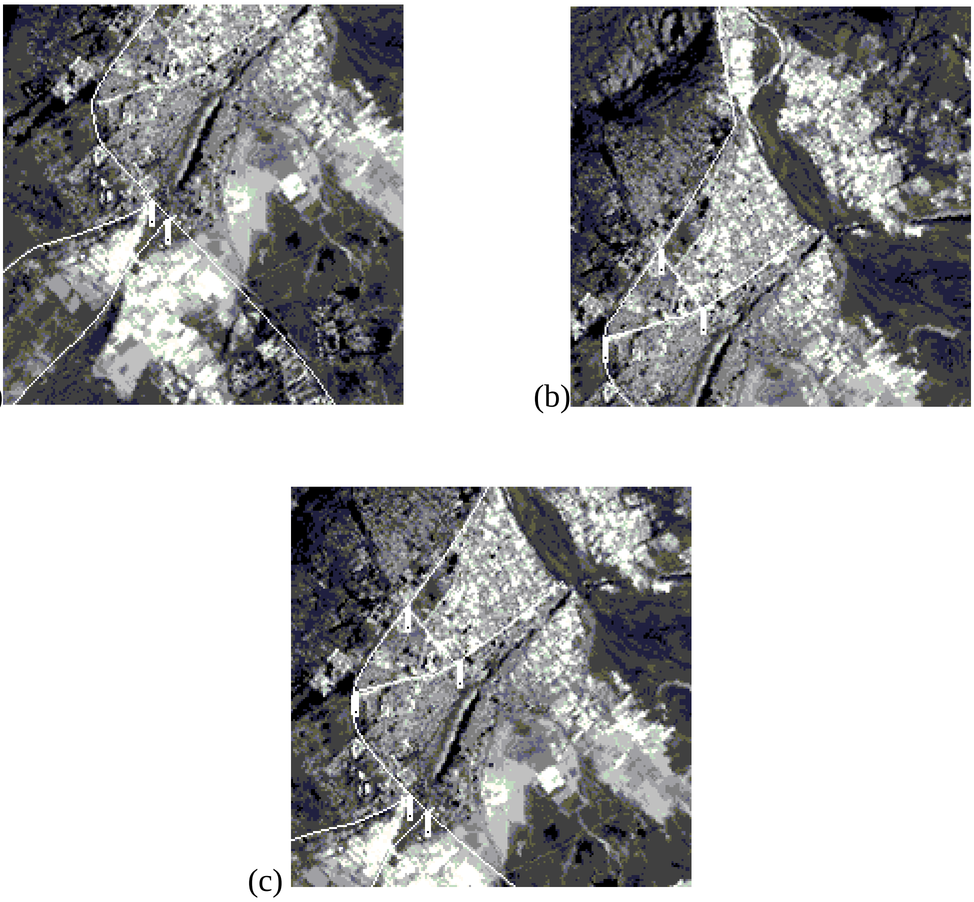
Fig.6. Road networks with their nodes extraction from a 200x200 satellite image:
(a) subimage of the original image in figure 5 and (b) the final result

The results in figure 6 demonstrated that the presented road network with its nodes extraction algorithm works very well.

Evaluation results:

The proposed method of a road network with its nodes extraction has been applied to satellite imagery. In total, three subsets of a satellite image have been tested. The source images cover portions of Laghouat area of the Algeria country. All of the extracted road networks and their nodes were quantitatively evaluated against our visual observations with the use of the mathematical morphology technique which adjusts the final result on the tested image (these tasks are very important because their use in GIS for the update).

Figure 7 shows the evaluation results from our test data sets. The evaluation shows that the road networks with their nodes have been extracted with a satisfactory accuracy. However false extractions are mainly from the boundaries of the other objects in image.



(a) (b) (c)

Fig.7. Evaluation results: (a), (b) and (c) overlapping the scene in (a) and (b) of figure 6

Various criteria have been used in previous studies to evaluate the performance of road extraction models. For guarantees, correctness, completeness and quality of road extraction, this paper presents the proposed semi-automated approach with its evaluation.

Comparing the extraction results of some previous methods, the evaluation shows that our proposed method gives satisfactory results in terms of accuracy and completeness. In fact, the efficiency is measured by comparing the total time cost consumed (treatments are doing in parallel way).

Performance evaluation:

The proposed approach needs less time with little errors for extract objects (roads, road network and nodes) very well. However, the difficulty for this new algorithm is a complicate method in its principle because it needs some parameters which make it semi-automated approach. So, in some cases the detection and connection are hard in particularly when the initial image is very blurred (many noise edges) and complicated road network scene (many building and trees among roads); in fact some road information is lost.

4.2 Discussion

In experiments, by comparison to some existing methods concerning extraction road network from satellite images, the studied methodology can have better detection results in different levels (simple and complicated test images). It achieved good degree of success according to the level of extraction and optimized calculate time due to the use of our proposed criteria which are beneficial. The main disadvantage of this proposed methodology is that the algorithms are more complex and difficult because to their parameters which they must be changed in function of resolution of image, its type, and its size.

Conclusion

The main interest of this work is to solve the problem of automatic mapping from satellite images (automatic update of a roadmap). To solve this problem, we have proposed an approach for roads, their road network and its nodes extraction from satellite images of areas in Algeria. The approach is an amelioration of our previous research works.

Research on the automatic extraction of road networks from remotely sensed imagery has been a topical research theme in the various fields of photogrammetric, remote sensing, geographic information systems GIS, pattern recognition, and computer vision.

This paper has presented a semi-automatic method which has used the two concepts: information theory and mathematical morphology. All treatments for extraction the three objects (roads, road network and nodes) are doing in parallel way.

Experiments are performed to extract roads, road networks with its nodes from satellite images. The results obtained were in general good. They show that the combination of few algorithms can more efficiently extract these objects than the multiple or individual algorithms. In fact, the proposed method is compared with some existing methods and particularly with our previous works; the comparison results are quantitatively evaluated in terms of computation time and level of extraction.

The current limits of our strategy are that it can't deal well with images of very large size. It is hard to define the reasonable parameters for these images.

Future work will also include the development of the algorithms to treat other elements of the maps (water, vegetation, building, etc.).

References

1. Z. Nougrara, A. Benyettou, A. Abedellaoui and N.I. Bachari, "Development of georeferenced database of an extracted road network and its nodes from satellite imagery over Algeria sites", A.M.S.E. Journal, Advances B (Signal Processing and Pattern Recognition), vol.54, no.2, pp.1-13, 2011.

2. Z. Nougrara, A. Benyettou, A. Abdellaoui and N.I. Bachari, "An approach for an extracted road network and its nodes from satellite imagery and a model of integration of obtained results in a geographical information system GIS", Australian Journal of Basic and Applied Sciences, vol.5, no.11, ISSN 1991-8178, pp.1831-1837, 2011.

3. Z. Nougrara, A. Benyettou, A. Abdellaoui, N.I. Bachari and K. Lahmar, "Comparative Study between two Proposed Methods of an Extracted Road Network and its Nodes from Satellite Images of Algeria Sites for Contribution to the Elaboration of a Geographical Information System GIS", International Journal on Communications Antenna and Propagation (I. Re. C. A. P.), vol.2, no.2, ISSN 2039-5086, pp.123-126, April 2012.

4. X. Lin, Z. Liu, J. Zhang and J. Shen, "Combining multiple algorithms for road network tracking from multiple source remotely sensed imagery: a practical system and performance evaluation", Sensors 2009, vol.9, no.2, pp.1237-1258; doi:10.3390/S90201237, 2009.

5. D. Chaudhuri, N.K. Kushwaha and A. Samal, "Semi-Automated road detection from high resolution satellite images by directional morphological enhancement and segmentation techniques", IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol.5, no.5, ISSN 1939-1404, pp.1538-1544, doi:10.1109/JSTARS.2012.2199085, Oct. 2012.

6. Z. Li, W. Shi, Q. Wang and Z. Miao, "Extracting man-made objects from high spatial resolution remote sensing images via fast level set evolutions", IEEE Transactions on Geosciences and Remote Sensing, vol.53, no.2, ISSN 0196-2892, pp.883-899, doi:10.1109/TGRS.2014.2330341, February 2015.
7. J.B. Mena, "State of the art on automatic road extraction for GIS update: a novel classification", Pattern Recognition Letters, vol.24, no.16, pp.3037-3058, doi:10.1016/S0167-8655(03)00164-8, December 2003.
8. J.B. Mena and J.A. Malpica, "An automatic method for road extraction in rural and semi-urban areas starting from high resolution satellite imagery", Pattern Recognition Letters, vol.26, no.9, pp.1201-1220, doi:10.1016/j.patrec.2004.11.005, July 2005.
9. X. Jin and C.H. Davis, "An integrated system for automatic road mapping from high-resolution multi-spectral satellite imagery by information fusion", Information Fusion, vol.6, no.4, pp.257-273, doi:10.1016/j.inffus.2004.06.003, December 2005.
10. H. Guan, J. Li, Y. Yu, M. Chapman and C. Wang, "Automated road information extraction from mobile laser scanning data", IEEE Transactions on Intelligent Transaction System, vol.16, no.1, ISSN 1524-9050, pp.194-205, doi:10.1109/TITS.2014.2328589, July 2014.
11. X. Yang and W. Wang, "Road identification in aerial images on fractional differential and one-pass ridge edge detection", Journal of Applied Remote Sensing, vol.8, no.1, 12 PDF pages, doi: 10.1117/1.JRS.8.083597, June 2014.
12. J. Hu, A. Razdau, J.C. Femiani, M. Cui and P. Wonka, "Road network extraction and intersection detection from aerial images by tracking road footprints", IEEE Transaction on Geosciences and Remote Sensing, vol.45, no.12, ISSN 0196-2892, pp.4144-4157, doi:10.1109/TGRS.2007.906107, December 2007.
13. D. Li, "Remotely sensed images and GIS data fusion for automatic change detection", International Journal of Image and Data Fusion, vol.1, no.1, pp.99-108, doi:10.1080/19479830903562074, 2010.
14. Z. Li, W. Shi, Q. Wang and Z, Miao, "Extracting man-made objects from high spatial resolution remote sensing images via fast level set evolutions", IEEE Transactions on Geosciences and Remote Sensing, vol.53, no.2, ISSN 0196-2892, pp.883-899, doi:10.1109/TGRS.2014.2330341, February 2015.
15. J.K. Mandal, S. Mal and S. Dutta, "Toward implementation of security and storage efficiency for geographical information systems", A.M.S.E. Journal , Advances B (Signal Processing and Pattern Recognition), vol.47, no.3, pp.1-12, 2004.

16. A. Aït Ouahman, T. Agouti, M. El Adnani and A. Tikniovine, "A hybrid model of mathematical programming and multi-criteria decision analysis for the geographical information systems to multiple representations: industrial localization in Morocco", A.M.S.E. Journal; Modelling D, (Production Engineering and Management, Organization, Human and Social Problems), vol. 29, no.2, pp.1-18, 2008.