Intercontinental Geoinformation Days

http://igd.mersin.edu.tr/2020/

Road extraction through satellite imagery processing and visual interpretation

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Keywords
Remote sensing
Road extraction
Urban planning
Digital processing
Visual interpretation

ABSTRACT

Road extraction plays an important role in urban planning and city extension issues, as well as in road monitoring, traffic management and map updating. Technological advances may offer a wealth of data and techniques that could be implemented in road delineation and extraction projects. Among the various methods that have been developed for this purpose, remote sensing techniques and especially digital processing of satellite data could contribute significantly in this direction. This paper presents the study of a road network which concerns the city of Kastoria and its surroundings located in northwestern Greece. The study is of particular interest due to the city's physiognomy depicted in its structure and the special character of the road network in the city center. Landsat 8 imagery was used in order to detect and delineate the linear features through spatial enhancement, while semi-automatic techniques were applied to SPOTmaps products to extract the road network. The resulted data present the efficiency of using satellite imagery for road network delineation and combined with other data could be used in further studies concerning road maintenance and extension, change detection issues, as well as for cultural and touristic purposes.

1. INTRODUCTION

Among the various elements that play an important role in urban and peri-urban development is the extraction of information related to the corresponding road network. Technological advances may offer a variety of data and techniques that could be used for road delineation and extraction. Remote sensing could contribute significantly in this direction (Cleynenbreugel 1990; Wang et al. 2016).

Digital processing of optical satellite images and visual interpretation could offer valuable information regarding the road network of an area, its structure, possible changes over time, as well as the road connections it offers (Karagianni 2019).

Several approaches have been implemented in order to delineate road structures on satellite imagery which are closely correlated with the regional characteristics of the study area as well as the relevant technological development (Alshehhi et al. 2017; Hong et al. 2019). While some methods require extended time to be performed, others require extensive knowledge in terms of computational or programming literacy. Therefore, fast and effective techniques are valuable, especially in preliminary studies.

This paper presents the study of a road network which concerns the city of Kastoria and its surroundings located in northwestern Greece. The long history of the city and its wider area, as well as the special structure of the road network in the historic districts of the city center make this study of particular interest (Lazaridou and Karagianni 2014).

Landsat 8 imagery and SPOTmaps products were used in order to detect and delineate the linear features, while semi-automatic techniques were applied to extract the road network. The efficiency of using satellite imagery for road network delineation is presented in the results, which could be combined with other data in order to be used in further studies concerning road maintenance and extensions, change detection issues, as well as for cultural and touristic purposes.

2. STUDY AREA AND SATELLITE DATA

2.1. Study Area

Study area is located in medium-high altitude (630m) in the north western part of Greece, region of Western Macedonia and it concerns Kastoria city and its

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Cite this study

Karagianni A (2021). Road extraction through satellite imagery processing and visual interpretation. 2nd Intercontinental Geoinformation Days (IGD), 222-225, Mersin, Turkey

surroundings (Fig. 1). The city is located on a peninsula at the western shore of Lake Orestiada and it has a long cultural history, which is depicted in its structure (old city, newer city and urban extension). The lake which surrounds the city is included in the Natura 2000 network offering unique habitats for many endangered fauna and avifauna species (Ponce de León 2015).

The city has a high architectural and urban value. Rich elements of Byzantine culture (Byzantine Justinian walls and medieval churches) as well as traditional mansions of the 17th and 18th centuries, unique for their architectural design are located in the city center (Doltso & Apozari traditional districts) (Moutsopoulos 1989).

Figure 1. The location of the Regional Unit of Kastoria in Greece (left image) and the city of Kastoria in the red circle (right image) (Karagianni 2019)

2.2. Satellite Data

The data employed for this study concern Landsat 8 satellite imagery and SPOTmaps products covering the study area.

Landsat 8 satellite was launched on February 11, 2013 and carries two instruments: The Operational Land Imager (OLI) sensor and the Thermal Infrared Sensor (TIRS). These sensors both provide improved signal-to-noise (SNR) radiometric performance, quantized over a 12-bit dynamic range (4096 potential grey levels in an image compared with only 256 grey levels in previous 8-bit instruments). Improved signal to noise performance enables better characterization of land cover state and condition (USGS 2012). Satellite data acquired from Landsat 8 consist of eleven spectral bands with a spatial resolution of 30 meters for Bands 1 to 7 and 9. The resolution for Band 8 (panchromatic) is 15 m and for Bands 10, 11(thermal bands) is 100 m. Among the eleven spectral bands, Landsat 8 includes one band that measures the near infrared (Band 5-NIR) and two bands that cover different slices of the shortwave infrared (Bands 6 and 7-SWIR).

The image data that have been used in this study were downloaded free of charge from U.S. Geological Survey (USGS-Earth Explorer). They were acquired on 14-03-2014 (path: 185, row: 32) with level processing 1T-Standard Terrain Correction (systematic radiometric and geometric accuracy) and projection information: UTM, zone 34, spheroid & datum WGS 84. The image has excellent quality (image quality: 9).

The SPOT satellite observation system was designed in 1977 by CNES (Center National D'Etudes Spatiales) in France with the participation of Sweden and Belgium. It was the first European Earth-observation satellite programme. The system consists of a series of satellites and terrestrial installations for the control and programming of satellites, as well as the production and distribution of images. SPOT satellites are equipped with two independent imaging instruments (series of detectors operating with pushbroom scanning technique). They collect multispectral and panchromatic imagery, offering high geometric accuracy. Each image covers a square of 60 km or 120 km on a side with a ground resolution of 10 m for SPOT 1 to SPOT 4 and 2.5 m for SPOT 5.

The SPOTmaps data that have been used in this study were provided by the Technical Services Division of Kastoria Prefecture and they were acquired on 20-12-2012. SPOTmaps products derive from SPOT 5 color satellite images and include orthorectified coverage at a resolution of 2.5 m (Airbus Defence and Space 2013). They consist of three spectral bands and projection information: WGS84/UTM zone 34N. These color products are obtained after merging two separate images, a panchromatic image with 2.5 m resolution and a multispectral image (three spectral bands) with 10 m resolution.

3. DIGITAL PROCESSING METHODS

Delineation and extraction of the road network were done by implementing digital processing through non-automatic and semi-automatic techniques. Visual interpretation performed before and after the processing also contributed to the study.

Enhancement techniques are often used in feature extraction, locating areas or objects on the ground and gaining useful details. Image enhancement refers to the creation of new images from the original data, in order to increase the information that can be visually interpreted from the data (Lillesand and Liefer 1987). Spatial enhancement modifies the pixel values based on neighboring pixel values. It is largely related to spatial frequency within an image, which is the difference between the higher and lower value of a continuous group of pixels. Among the various techniques available, edge and line detection is a significant enhancement technique in digital image processing, especially in the study of urban features or in linear features mapping, such as road networks (Karagianni 2019).

In the first stage of the study, spatial enhancement techniques were applied to Landsat 8 imagery (after subsetting the data according to the area of interest) in order to improve the appearance of the image and facilitate the extraction of useful information regarding the linear features which are highlighted. Spatial enhancement operations improve the interpretability of features within the data by modifying neighborhood pixel values based on the value of a targeted pixel. Convolution filtering uses a matrix to average small sets of pixels across the image in order to change the spatial frequency characteristics (ERDAS Field Guide 2013).

The original Landsat 8 image subset, as well as the resulted image subset after the implementation of a 3x3 convolution filter, are presented in Fig. 2 and Fig.3 respectively. Edge detection processing highlighted linear features (including the road network) and urban features.

Subsequently, road extraction could be performed manually using the enhanced image as a base in order to create a vector layer which would contain the road network.

Figure 2. The original multispectral image covering the study area (color composite RGB: 4-3-2) (Karagianni 2019)

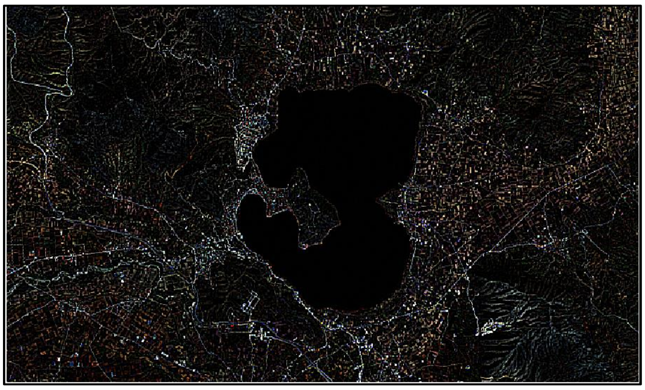

Figure 3. The final image after convolution filtering for edge detection (Karagianni 2019)

For the digitization of various features as well as related changes (changes in road networks, changes in infrastructure networks, urban development issues, etc.) classic, manual digitization techniques are frequently used, which can often be time-consuming and tedious.

Extraction of information from satellite images in vector format (digitization of linear elements and boundaries, such as road network, lake outline, etc.), could be accomplished through semi-automatic digitization techniques, in addition to the manual detection/design process through visual interpretation only. In this way, the process is simplified while the required time is reduced.

Most image processing software offer add-on modules that could facilitate the extraction of linear features through assisted digitization reducing the required amount of non-automated workload when collecting different types of features.

In this study, a module offered by Erdas Imagine software was used in order to digitize the road network of the study area. This interactive tool is guided by the operator who recognizes features from the screen image (IMAGINE Easytrace™ User's Guide 2010). The process was performed in SPOTmaps image as it offers higher spatial resolution and consequently higher accuracy in the results.

The definite and nearly constant width, as well as the similar texture (pattern) along the extension of the road network were exploited in order to draw ribbon features by centerlines, setting the appropriate parameters.

Boundary features such as road edges were detected through the discontinuity of intensity or color which indicated different areas, as well as due to the consistent texture (whiter or blacker than the background). Vertices were automatically inserted between the neighboring manually measured vertices based on the underlying raster imagery, in comparison to the classical digitizing method in which manually measured vertices are only used. The results were saved in a vector file. In Fig. 4 the digitized road network is presented in yellow color, while in Fig. 5 the area of the city extension is shown (subset of the newer part of the city) which presents a more organized structuring.

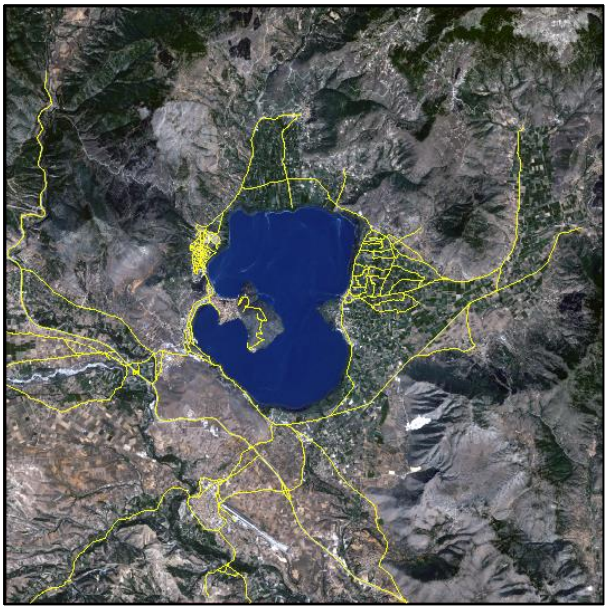

Figure 4. Road network of the city of Kastoria and the wider area (yellow line) on the SPOTmaps satellite product (Karagianni 2019)

Figure 5. Road network of the city extension (yellow line) on the SPOTmaps satellite product subset (Karagianni 2019)

4. DISCUSSION-CONCLUSION

Several methods could be applied to satellite images in order to delineate and extract road networks for urban planning and road monitoring. In the selection of the most appropriate method several parameters should be taken into account, such as the type of the project, the study area, the available time and the required workload, as well as the final cost and the specialization of the personnel. Therefore, the need to search for easy, fast and efficient tools is imperative.

Spatial filters could be used to sharpen or emphasize the edges in the image, offering effective results especially in preliminary studies which do not require special details but must be carried out in a short time. In this study, convolution filtering for edge detection was applied in order to delineate the linear features. The resulting image after spatial enhancement presents an improved appearance and is suitable for the delineation of linear features. The road network is effectively highlighted facilitating the subsequent manual extraction process.

Semi-automatic digitization offers satisfactory results in the urban areas of the imagery, where the urban fabric presents organized structuring (as shown in Fig. 5). Satisfactory results are also obtained in areas where there is a strong differentiation between the road network and the environment (road network in cultivated areas, in the mountainous area of the peninsula or in bare ground areas).

In intricately structured areas presenting a more anarchic structuring (road network of narrow width and shading interference), the semi-automatic method appears to have weaknesses in digitization as there are difficulties in finding the edges (center of urban fabric on the peninsula). Similar problems also arise when attempting to digitize sections of the road network with variable width or large differences in texture.

Especially in multispectral images, features that are normally sharp enough to be clearly visible on the screen may not be properly detected, as the module processes image intensity information only (large color differences may not correspond to large intensity differences). This issue could be solved if one of the color bands is used for digitization or if the image is digitally enhanced before digitization. Additional corrections to digitization can also be made manually, combining the semi-automatic with the manual process.

Through semi-automatic digitization, the process is facilitated and the amount of non-automated workload required when collecting different types of features could be reduced, providing products which could be efficiently combined with other types of data for road maintenance and extension, change detection issues, as well as for cultural and touristic purposes.

ACKNOWLEDGEMENT

The author wishes to thank the former Technical Services Division of Kastoria Prefecture (now Directorate of Technical Works, Regional Unit of Kastoria) for providing the SPOTmaps products.

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