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Computing street centrelines from interstitial area

Application to the street network schematisation in the Metropolitan District of Quito (Ecuador)

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ABSTRACT

This paper describes the foundations and the implementation of a GIS method that allows the generation of a network from an interstitial area. The method was specially designed to automatically create the urban road network using a georeferenced cadastre in a vector format. This tool is very useful for urban management authorities as it avoids the tedious manual digitising process or the frequently-used GPS acquisition survey (road tour) and as it also ensures an optimal overlay between the roads and blocks layers. The functionality was implemented in *SavGIS*, a GIS freeware developed by IRD (Institut de Recherche pour le Développement, France) within the framework of the scientific cooperation with southern countries.

KEYWORDS

GIS, *SavGIS*, street centrelines automated computing, interstitial area, skeleton, urban road network, cadastre, urban managers, Quito, Ecuador.

INTRODUCTION

The schematisation of street network in urban areas is an important concern for urban planners. Indeed, it allows to compute distances, calculate shortest paths, organise the roads maintenance, manage the transportation of hazardous goods, and assess the accessibility… The road digitisation or capture process is definitively one of the longest and expensive tasks to build up a location-based database. In that way, every automated procedure represents a real interest for both northern and southern countries. Indeed, in the formerly industrialised countries, the labour force is expensive while in the developing countries the very quick urban sprawl makes difficult the update of municipal urban geographical databases. In northern countries, lots of private companies offering services or authorised GIS resellers provide urban road network already in georeferenced vector formats while in southern countries, the offer is often more reduced and the municipal budgets are generally lower.

In that frame, the example of the urban management carried out by the Municipality of Quito, capital of Ecuador, is particularly demonstrative as detailed further on. Located at 2,800 metres above sea level, the Metropolitan District was sheltering 1.5 million inhabitants over 4200 km² in 2001, while in 1868 the town was gathering only 45,000 inhabitants settled on 4 km². The Metropolitan Urban Studies Bureau of the Municipality of Quito has been managing over the last 15 years jointly with IRD a spatial-referenced database meant to support urban management and planning [6]. This database is structured and managed with a GIS freeware called *SavGIS*, developed since 1984 by IRD within the framework of the scientific cooperation with southern countries [11]. Since 2001, the municipality is carrying out a vast programme of land registry parcels digitisation all over the district. At the beginning of 2005, about 350,000 parcels were already digitised. This work is fundamental as it underpins the assessment of the real tax that was becoming to be exaggeratedly low depriving thus the municipality of incomes in a context of growing needs.

One of the major problems to be first observed by the municipal technical staff was the bad overlay between existing road network and the newly digitised parcels especially in the outskirts (Figure 1). This bad overlay is mainly due to the current georeferencing techniques which are now much more accurate than those used 15 years ago. Besides, in the recently built areas, no street map was available. For these two reasons, the Municipality of Quito, instead of starting a manual road network capture, attempted to take advantage of the up-to-date cadastral database in order to generate automatically a street centreline layer. The objective was to get lines with a unique identifier, delimited by each crossroad and exactly positioned at the medial axis of the street. However, this peculiar geo-processing was not available in commercial GIS software. Most of GIS software allow to compute polygons deriving from the public space between blocks (negative o inverted layer of the parcels layer), but none of them perform this specific geo-processing. To address this issue, IRD developed an ad hoc functionality in *SavGIS*, as described in the following section.

Figure 1 – Example of the bad overlay between the manually digitised streets (ten years old, in blue) and the recently digitised parcels (in black) in the North of Quito.

METHOD AND ALGORITHMS

The definition of the medial axis between polygons is a well-known problem in the ambit of robotics [1], [3]. It is a question of defining the set **A** of points **M** belonging to the space which is not included in the initial domain **D** and which are at an equal distance from at least two points $\mathbf{P}_1$ and $\mathbf{P}_2$ of the domain, with $d(\mathbf{M},\mathbf{P}_1) \leq d(\mathbf{M},\mathbf{P})$ for every point **P** of **D**. Applied to a great number of polygons, the geometrical solution for medial axis computation is tough, and even harder in the case of cadastre made of a very high number of arcs (block boundaries).

General method

The problem of the geometrical complexity is classically solved using first a raster layer to represent the inverse of the initial domain of blocks referred to as **I** (the interstitial area, corresponding to the streets area), and second by skeletoning **I** through an iterative process [9]. The skeleton thus generated is afterwards vectorised and the network topology completed. To do so, the pixels belonging to the skeleton are converted to points or nodes and are connected to each other. A node (end of a lines) is a point which links more than two other points. Nevertheless, the pixel to point process implies a loss of accuracy. The required accuracy for a street network is determined by the urban manager's needs (decimetres or even less). Over an area like the Metropolitan District of Quito (4200 km^2), such an accuracy would require the handling of a huge image of about 10^{10} pixels (which is almost impossible to process rapidly with a common computer). It is therefore necessary to divide the process and to split the domain in tiles with an overlap that ensures the stability of the global skeleton processing and the proper merge of lines once vectorised.

The global process relies on the eight following steps:

1. Partition of the whole study area in square tiles, with an overlap of 25 % in X and Y. The partition depends on the required accuracy, as indicated above.

2. For each square tile, creation of a binary image representing the interstitial area between parcels. A first image is created using a process of polygon rasterisation. This first output image represents the blocks area (figure 2).

Figure 2 – Example of parcels filled in grey with interstitial areas represented in white (South of Quito).

This image is afterwards inverted to represent the interstitial area between blocks. The raster resolution (pixel size) depends on the required accuracy for the final result (the street network), and is set by user. The number of square tiles is a direct function of the raster resolution.

3. Restriction of this image to a buffer extent. This step is necessary only if the process is performed over a specific area (in our example, over the central area of Quito, not over the whole Metropolitan District). A buffer is therefore created for every tile, and overlaid to set to zero the pixels that are outside the buffer.

4. For each tile, a line thinning (skeletonisation) is applied using a global iterative mark-and-delete method. This process is divided into two steps. First, lines are thinned by parallel method (Zhang-Suen algorithm), then post-processed for staircase removal (Holts post-processing method) [9]. Skeleton calculation is the main operation of the whole process, and the most time consuming task.

5. Restriction of the skeleton to the centre of the tile (the parts of the skeleton located in the outer parts of the tile -25%- are removed),

6. After thinning, an automatic vectorisation can be easily performed by contour tracing, as the resulting skeleton has a constant width of one pixel. A node is created when a pixel is connected to

more than two other pixels. The vectorisation process creates lines in geographical coordinates, with a unique identifier for each one.

7. The adjacent lines which were arbitrarily divided by the partition process are merged (snapping process).

8. Filtering (by triangle surface) and generalisation (Lang algorithm) end the process of line generation [7] (figures 3 and 4).

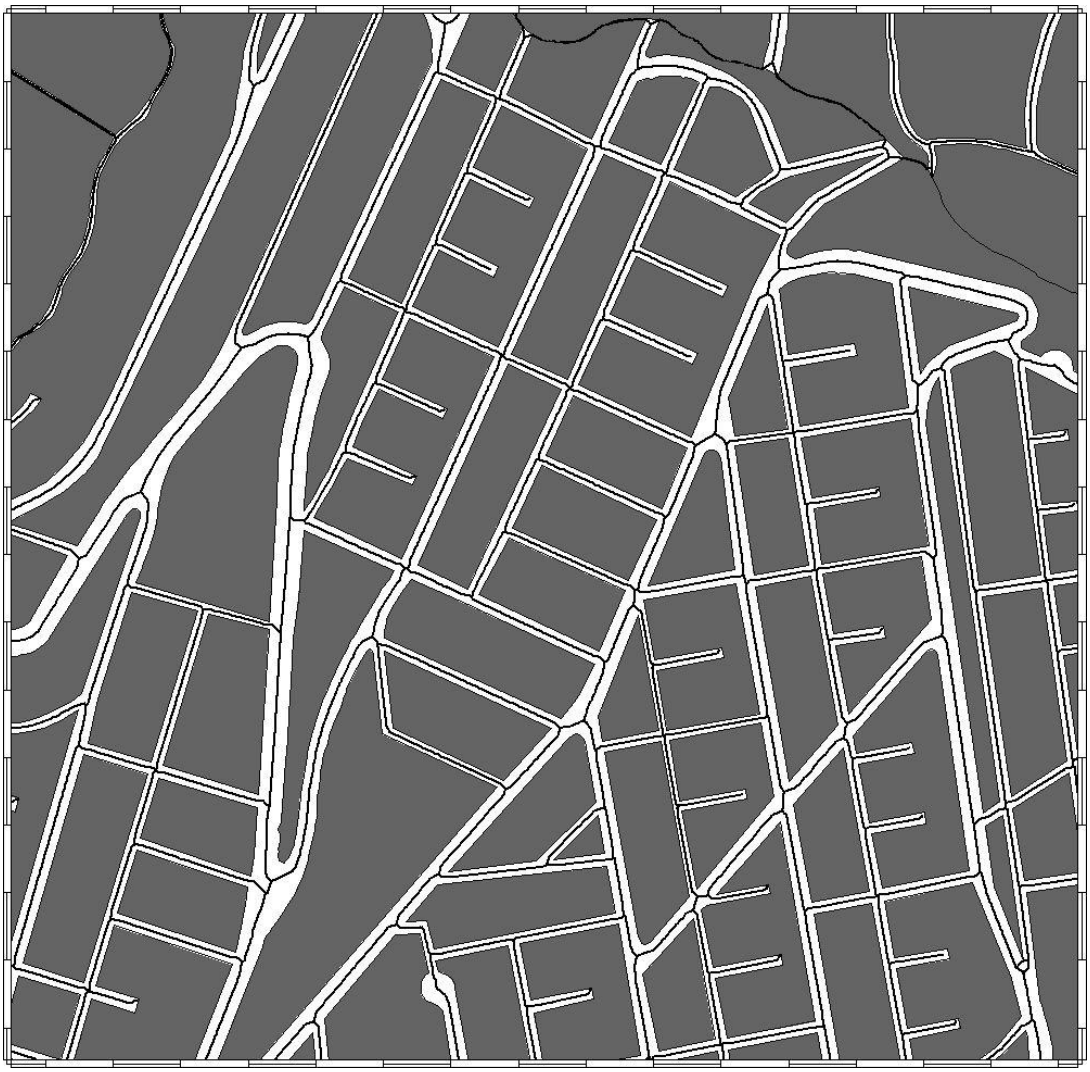

Figure 3 – Examples of street centrelines automatically generated from interstitial area between parcels filled in grey (detail of an area in the South of Quito).

Figure 4 – Example of street centrelines automatically generated from interstitial area (South of Quito).

Implementation in SavGIS

All these processes were implemented in the SavGIS software [10].

SavGIS is a multipurpose GIS software developed by IRD since 1984 in order to fulfil academic and scientific needs, within the frame of research programmes carried out by IRD in developing countries. It offers a full MS Windows-based GIS freeware solution, opened to new developments, and downloadable from the Internet[1].

SavGIS is based on the theoretical principle of the relational database management extended to spatial objects. It includes its own spatial bi-dimensional database engine. All objects are stored using a bi-dimensional indexed structure. It offers a wide set of database management, digitisation, spatial analysis, and mapping options. It supports both vector and raster formats. Objects are managed as objects collections (layers), whatever their spatial type (zone, line, point, or pixel). Some processes relies directly on the internal vector representation of the objects, others – as the one presented in this paper – relies on a temporary raster representation [11].

SavGIS works on the basis of interactive queries: a whole query is split into successive elementary operations (restrictions, joins, classifications, attribute creations, etc.), allowing an empirical approach. The generation of street centrelines from interstitial area relies on such successive steps.

[1] http://www.savgis.org/SavGIS/accueil.html

This operation creates a new temporary layer which can be afterwards exported to be edited, or directly integrated into the database as a permanent layer. Street centrelines generation process makes use of rasterisation, skeleton generation and contour tracing procedures as described below:

Rasterisation: in SavGIS, all polygon boundaries are stored using arcs. Internal resolution of the rasterisation process is set at 2000 pixels. The rasterisation process in a tile implies reading the arcs of every objects intersecting with the tile, transforming every arcs in points by horizontal rasterisation, and calculating the inner part of the objects from this point using an YX algorithm.

Skeleton and contour tracing: this process creates a new layer in the database, with spatial index based on the tile partition.

The most time consuming process is associated with the skeleton generation. The duration of the process depends directly on the number of skeleton to be created, and on the number of tiles generated by the partition which depends on the accuracy set by the user.

APPLICATION TO THE CITY OF QUITO

The Metropolitan Urban Studies Bureau of the Municipality of Quito has been managing and updating over the last 15 years jointly with IRD a spatial-referenced database meant first to support urban management, mobility analysis [5] and more recently for risk management. This geo-database includes a vast set a data such as administrative divisions, cadastre, socio-economic and housing data from census, networks (roads, sewage and electric systems, water supply…), environmental data (DEM, hydrological network, meteorological data, geology) and hazards maps (floods, landslide, lahars…). Since 2001, the municipality is carrying out a huge programme of parcels digitisation all over the district. At the beginning of 2005, about 350,000 parcels were already digitised. We applied our algorithm to this new layer. We set a 20 cm spatial resolution. As a result, more than 6000 tiles were generated and more than 40,000 lines were created.

Accuracy and duration of the process: the duration of the process and the quality of the output street network depends obviously on the number of tiles created with the partition. The duration of the skeleton calculation is determined by the area of the interstitial space as this is an iterative process. The number of input objects (the blocks in our case) only has an indirect influence on the overall duration: the computing time varies in the extent of the square of the spatial resolution set by user. For the whole central area of Quito (11,500 blocks spread over 15,800 ha), the process took about 2 days.

Quality: the skeleton process generates a line in the centre of the interstitial area. This gives a very satisfying result for street shape except on crossroads where the skeleton depends on the local configuration of the street junction. In those cases, the output street centrelines does not match a realistic road shape as showed in figure 5. An additional algorithm is therefore required to improve the process for street junctions. Nevertheless, the current output is optimal in order to calculate distance. In addition, in the case of the city of Quito, the output street network thus generated is much more satisfying than the manually previously digitised network.

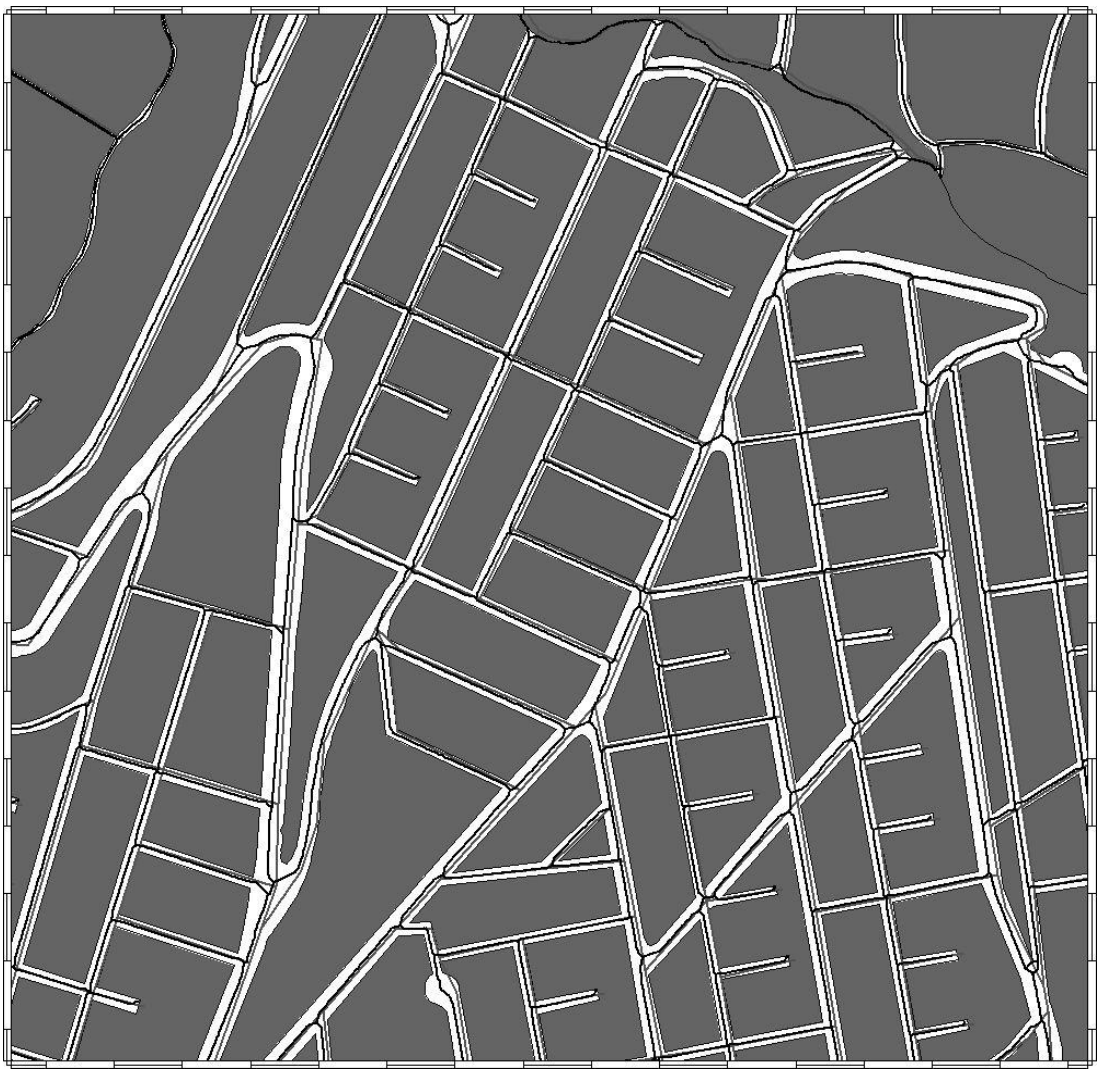

Figure 5 – Comparison between street centrelines generated from interstitial area (black lines) with manually digitised streets (grey lines) in the South of Quito.

CONCLUSIONS AND PERSPECTIVES

The aim of this paper was to describe the technique we implemented in SavGIS to automatically generate an urban road network based on the interstitial area derived from cadastral plans. This procedure easy to perform avoids the road digitisation which is one of the most time consuming and expensive tasks to build up a location-based database. This peculiar spatial processing generates segments delimited by each crossroad and labelled with a unique identifier and the output layer overlays properly with the parcels one. This kind of georeferenced street layer could be used for field surveys organised in order to report for instance the state of the traffic lanes prior to road repair. Others data could also be collected on the field (width of the street). However, those measurements remain fastidious even with modern devices (laser). That is the reason why a new spatial processing is being currently developed in *SavGIS* in order to automate the calculation of the street width. This information is crucial for urban managers as it governs the use to be done of the remaining vacant parcels or the use of the blocks to be built (size and type of construction in reference to the parking lot requirements …). In a general manner, to know the width of traffic lane provides numerous possibilities (selection of the itineraries for exceptional convoys, calculation of the level of service considering the traffic volumes…).

The present paper described an operational example of a geomatics applied to urban management.

Nevertheless, our algorithm should be improved to get even more realistic street network schematisation and to ensure the straightness of the main avenues at the crossroads.

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