VECTORIZATION OF BUILDINGS USING HIGH-RESOLUTION DIGITAL PHOTOGRAMS

L. DRAGOMIR[1,] Alexia ABĂLARU[*], R. BERTICI[1], D. DICU[1], G. POPESCU[1]

University of Life Sciences "King Mihai I" from Timisoara, Timișoara, 300645, Romania
[1)] Department of Sustainable Development and Environmental Engineering
[*]Corresponding author: mihai_herbei@yahoo.com

Abstract. *Currently, software applications are widely used, among which we mention the navigation systems on vehicles , traffic monitoring and management systems, etc., which require the use of road databases. These databases must contain accurate, updated information and populated with sufficient descriptive values. This article presents a semi-automatic algorithm for extracting roads from high-resolution aerial and satellite recordings, based on the weighted correlation of cross-sectional profiles. The algorithm uses as initial data two starting points with the help of which the road orientation and the template profile are obtained. Also, the operator must set the threshold value of the correlation coefficient between the transverse profiles, the pitch and the search angle, the length of the transverse profile and the maximum number of rejections Compared to other semi-automatic road vectorization algorithms, this algorithm is less sensitive to changes radiometrics from the ends of the profile, due to the assignment of higher weights to the central pixels. In this article is proposed an algorithm for semi-automatic vectoring of roads on color aerial images with submetric resolution, an algorithm that uses the weighted correlation of road cross profiles with a template profile. The operator must provide two points successive start, as close to the center of the road as possible, with the help of which the direction of start and template profile.*

Keywords: *road, resolution, vectorization, analyze*

INTRODUCTION

Automated extraction of roads from aerial and satellite imagery has been an important research direction in the field of photogrammetry for the last few decades. Typically, three stages of the collection process can be distinguished (11, 9): road identification, road tracking (road tracking) and road connection (road linking). The diversity of source images, both in terms of spatial resolution and radiometric resolution, has led to the emergence of several types of algorithms for vectoring roads on aerial images or satellite.

When the human factor is involved in the process of identifying the road, then the algorithm it is semi-automatic, otherwise one can talk about an automatic approach to the extraction of roads.

There are a multitude of algorithms used for semi-automatic and automatic extraction of roads on air and satellite recordings, and an exhaustive classification of them is presented by J. B. Menel (7).

Semi-automatic road-gathering algorithms use start points and directions start provided by the human operator in the road tracking process. Semi-automatic method proposed by Vosselman and Knecht (10) uses the similarity of cross profiles and filtration Kalman for the road-tracking. Their method consists in calculating the positions of the road by comparison of a template profile obtained by mediating the profiles of a road segment reference with profiles extracted from the image. Road parameters are estimated using a Kalman filter recursively.

The predictive power of this filter allows the continuation of the path tracking even if sometimes no profiles similar to the template profile are found until a termination criterion is met.

McKeown and Denlinger (6) have proposed a method that consists of using the latest positions the road for determining a parabola and extrapolation of the next position of the road on the basis of this parable, and Gruen and Li (5) applied a "snake" pattern and the method of the smallest squares to extract 3D roads from stereomodels formed by aerial images.

If the starting points are determined automatically, then the methods of collecting the roads they're automatic. Start points can be detected automatically using the gray values histogram (2). In Baumgartner and others (3), the roads are shaped by a network of intersections and connections between these intersections and determined by grouping processes. Amini and others (1) use an approach object-based for automatic extraction of main roads.

In a first stage, the source image is segmented and straight line segments are extracted. In the second stage, the spatial resolution of the source image is degraded, and the degraded image is transformed into a binary image. The axle (skeleton) of the road from the binary image is then extracted. By combining the results of these two stages, the road edges are obtained.

In general, in the methods of road tracking is made the assumption that the properties radiometric and road direction will not change abruptly, hypothesis satisfactory to most sections of the road network.

In this article is proposed an algorithm for semi-automatic vectoring of roads on color aerial images with submetric resolution, an algorithm that uses the weighted correlation of road cross profiles with a template profile. The operator must provide two points successive start, as close to the center of the road as possible, with the help of which the direction of start and template profile.

MATERIAL AND METHODS

PRESENTATION OF THE PROPOSED SEMI-AUTOMATIC VECTORING ALGORITHM

The algorithm for semi-automatic vectoring of the roads on the aerial records, or very high-resolution satellites in digital format consist of the following stages, highlighted in fig. 1.

a) In the selection and setting stage of initial data, two starting points $P_1(x_1,y_1)$ are chosen, and $P_2(x_2,y_2)$, the minimum correlation threshold between the cross profiles $\mathbf{r_{prag}}$, length **L** of the profile transverse of the vectorized road, length **d** of the search step, maximum number of rejections **m** and the angle of search $\mathbf{a}$.

b) Based on the starting points, the initial orientation is determined $\boldsymbol{\theta_2}$ and the profiles are extracted perpendicular to the direction of $\mathbf{P_1P_2}$ in points $\mathbf{P_1}$ and $\mathbf{P_2}$, by means of which the template profile is calculated which will be correlated with the search profiles, according to fig. 2.

The template profile is considered the profile obtained at the $\mathbf{P_2}$ point or the profiles obtained are mediated in the two initial points. Initial orientation $\boldsymbol{\theta_2}$ is obtained using the following relation:

$$\theta_k = arctg\frac{x_k - x_{k-1}}{y_k - y_{k-1}}$$

in which k = 2.

c) The points $A(x_A,y_A)$ and $B(x_B, y_B)$ are determined, their coordinates being obtained with relationship aid:

$$A:\begin{cases} x_A = x_{P_k} + d\cdot\sin\left(\theta_k - {}^{\alpha}/_{2}\right) \\ y_A = y_{P_k} + d\cdot\cos\left(\theta_k - {}^{\alpha}/_{2}\right)\end{cases} \qquad B:\begin{cases} x_B = x_{P_k} + d\cdot\sin\left(\theta_k - {}^{\alpha}/_{2}\right) \\ y_B = y_{P_k} + d\cdot\cos\left(\theta_k - {}^{\alpha}/_{2}\right)\end{cases}$$

The results obtained for k = 2 are exemplified in fig. 2.

Next, the number of **t** pixels that exist along the **AB** segment is determined the basis of the spatial resolution of the source image and the distance of the **AB** segment.

Calculate the center coordinates of each previously determined pixel. In the case of an image pancromatic, for each center S,(x,,ays,), i=1…*t* orientation of the P_kS_i segment; (k≥2), extract the profile perpendicular to the direction of P_kS_i and calculates the correlation coefficient between the cross template profile and the current profile using next relationship:

$$r = \frac{\sum_{i=1}^{n} p_i^2 g_i q_i - \frac{1}{n}(\sum_{i=1}^{n} p_i\, g_i)(\sum_{i=1}^{n} p_i\, q_i)}{\sqrt{\left[\sum_{i=1}^{n}(p_i g_i)^2 - \frac{1}{n}(\sum_{i=1}^{n} p_i\, g_i)^2\right]\left[\sum_{i=1}^{n}(p_i q_i)^2 - \frac{1}{n}(\sum_{i=1}^{n} p_i\, q_i)^2\right]}}$$

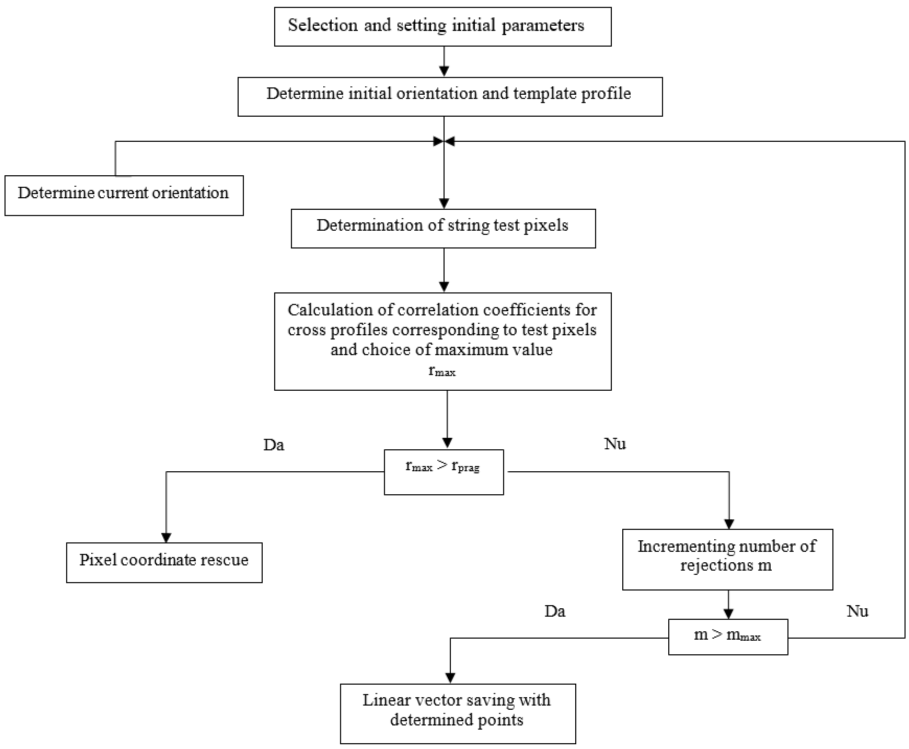

Fig. 1 Semi-automatic vectoring algorithm by profile correlation method

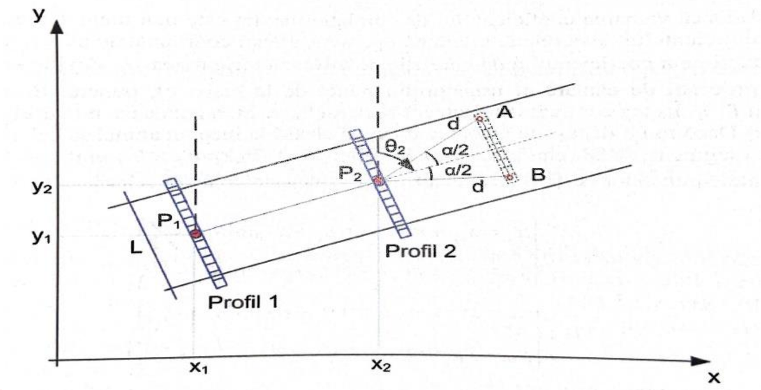

Fig. 2 Geometric exemplification of input data

In relation (3) n represents the number of pixels in the template profile, g_i, and q_i, i=1…n the gray values of the pixels in the correlated profiles and p_i represent the weights associated to each pixel from the correlated profiles, $\sum_{i=1}^{n} p_i = 1$.

If an odd number of pixels n are considered to exist in a profile, the scaling factor of the weights of the marginal and central pixels are $b \geq 1$ (fig. 3) then the weight of each pixel in a cross profile is calculated by formula:

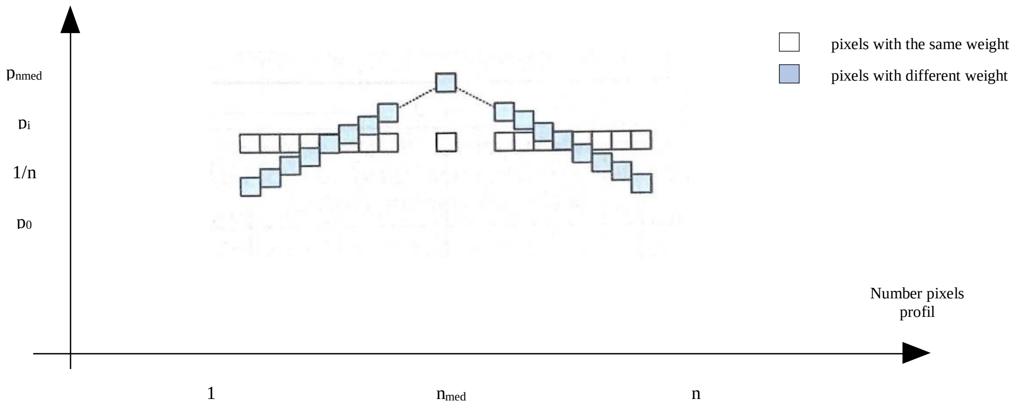

Fig. 3 How to set pixel weights along a profile

$$p_i = \begin{cases} p_0 + i \cdot u, for\ i = 1 \dots n_{med} \\ p_0 + (n - i) \cdot u, for\ i = n_{med} \dots n \end{cases}$$

where n_{med} = trunc(n/2), $p_0 = \frac{1}{b \cdot n}, u = \frac{b-1}{b \cdot n_{med} \cdot (n_{med}+1)}$. The central pixel will have the weight $p_{n_{med}} = p_0 + 2 \cdot u \cdot n_{med}$.

For a RGB color image, a correlation coefficient is calculated for each spectral band following that the product of the three correlation coefficients is considered the coefficient the final correlation. The **S_i** point is retained; in which the value of the correlation coefficient between the profiles is maximum (fig. 4).

d) If the value of the maximum correlation coefficient is greater than or equal to the threshold of the correlation coefficient set by the operator, then the coordinates of point S_i; corresponding the maximum value of the correlation coefficient is saved, the orientation θ_{ki} becomes the current orientation and resume the search process for the next point at stage c), point S_i; previously determined becoming P_{k+1}. Otherwise, the S_i point is rejected, the number of rejections **m** is incremented.

e) If **m** does not exceed the maximum value chosen at the beginning then the coordinates are calculated another segment **A'B'** according to fig. 5. The P_kP_j segment (j=k+m) has the length **m·d** and the coordinates of points **A'** and **B'** result from the application of the following relations:

$$A:\begin{cases} x_A = x_{P_k} + m \cdot d \cdot \sin\theta_k \cdot \sin\left(\theta_k - {}^{\alpha}/_{2}\right) \\ y_A = y_{P_k} + m \cdot d \cdot \cos\theta_k \cdot \cos\left(\theta_k - {}^{\alpha}/_{2}\right) \end{cases}$$

$$B:\begin{cases} x_B = x_{P_k} + m \cdot d \cdot \sin\theta_k \cdot \sin\left(\theta_k - {}^{\alpha}/_{2}\right) \\ y_B = y_{P_k} + m \cdot d \cdot \cos\theta_k \cdot \cos\left(\theta_k - {}^{\alpha}/_{2}\right) \end{cases}$$

where m is the number of rejections.

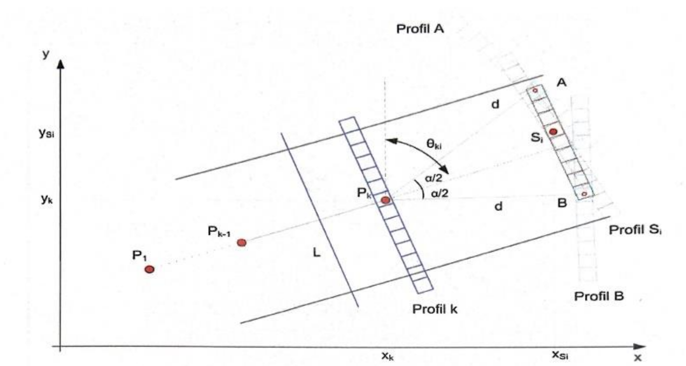

Fig. 4 Determining the pixel in which the correlation is maximum

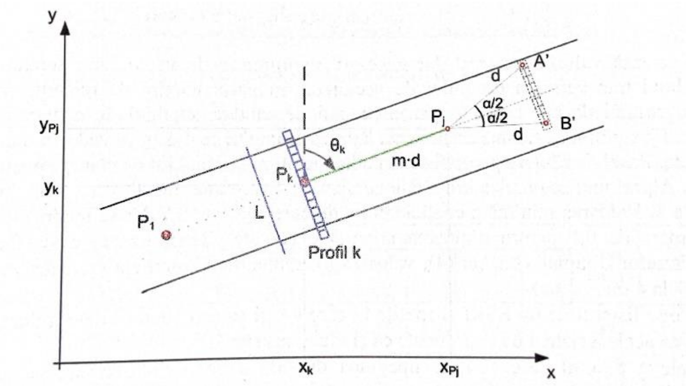

Fig.5 Determination of the segment with search pixels in case of successive rejections

Return to stage c) for determining correlation coefficients for profiles the **A'B'** segment.

If **m** exceeds the initially selected maximum value, the vectoring algorithm stops and stops saves the initial points and those determined by correlation in the form of a linear vector.

RESULTS AND DISCUSSIONS

There were automatically vectorized a number of 7 segments of roads located in the western area of Brăila city (fig. 7).

Table 1 presents the initial data for which optimal results were obtained by running **ExtractRoads** application, vectoring times and maximum error measured against the center the road.

where the initial parameters are as follows: **L**-length profile transverse road; **d** - step by search; $\mathbf{r_{min}}$ - minimum correlation coefficient; **θ**- search angle; **b** - scaling factor; $\mathbf{m_{max}}$ – number maximum rejection; $\mathbf{t_{gen}}$ - generalization tolerance.

The influence of the input parameter values is analyzed in the following.

Thus, the length **L** of the cross profiles along the roads must be larger about 10-20% of the road width to ensure better correlation and get points as much closer to the middle of the road. Setting values outside the range indicated above may it causes premature stopping of the algorithm and obtaining vectors with small lengths.

Fig. 7 Study area and vectors obtained

It has been observed that vectoring results are better in case of choosing a lookup step value d greater than half of the profile width but less than the profile width. Otherwise, points which are not found on roads but which have similar spectral characteristics may be retained, especially in the case of natural roads which are bordered by clear surfaces.

Table 1

Initial parameters and vector data

Nr. Seg.	Coordinates start points		Initial parameters							Time (sec)	Maximum error (m)
			L (m)	D (m)	r_{min}	θ (°)	b	m_{max}	t_{gen} (m)		
1	$A: \begin{cases} x = 573387{,}1 \\ y = 5015301{,}2 \end{cases}$	$B: \begin{cases} x = 573294{,}9 \\ y = 5015346{,}3 \end{cases}$	12	7	0,84	25	1,4	2	2	43	1,8[2]
2	$A: \begin{cases} x = 573212{,}4 \\ y = 5015389{,}1 \end{cases}$	$B: \begin{cases} x = 573228{,}6 \\ y = 5015423{,}3 \end{cases}$	10	7	0,84	25	1,5	2	1,5	12	1,6
3	$A: \begin{cases} x = 572532{,}6 \\ y = 5015159{,}2 \end{cases}$	$B: \begin{cases} x = 572552{,}1 \\ y = 5015202{,}1 \end{cases}$	13	7	0,82	30	1,6	3	2	32	1,9
4	$A: \begin{cases} x = 573030{,}6 \\ y = 5016179{,}2 \end{cases}$	$B: \begin{cases} x = 573009{,}2 \\ y = 5016129{,}2 \end{cases}$	13	7	0,84	30	1,4	3	2	20	1,2
5	$A: \begin{cases} x = 572978{,}5 \\ y = 5016062{,}5 \end{cases}$	$B: \begin{cases} x = 572997{,}3 \\ y = 5016053{,}2 \end{cases}$	8	4	0,89	25	1,4	2	1	21	1,3
6	$A: \begin{cases} x = 573261{,}3 \\ y = 5015149{,}2 \end{cases}$	$B: \begin{cases} x = 573260{,}2 \\ y = 5015174{,}5 \end{cases}$	8	5	0,89	25	1,4	2	1	9	1,6[3]
7	$A: \begin{cases} x = 572440{,}5 \\ y = 5016226{,}5 \end{cases}$	$B: \begin{cases} x = 572429{,}8 \\ y = 5016196{,}2 \end{cases}$	9	5	0,89	25	1,4	3	1	12	1,6

It is indicated that the threshold value of the correlation coefficient is greater than 0.8 in order to obtain geometrically and semantically correct vectors. For hard roads (asphalt, concrete) the rmin value is between 0.8 and 0.86 and for natural roads, the I'min value must not be less than 0.85.

The number of pixels to be tested (fig. 4, segment AB) directly depends on the value of the search angle. Thus, the higher it is, the higher the number of test pixels. For roads without sinuosities it is recommended that the value of this angle be small by 20 - 25°.

The weight scaling factor actually determines the influence of the marginal pixels in the correlated cross profiles. Values higher than 1.6 are not indicated because the share of marginal pixels is significantly reduced and values lower than 1.2 lead to a considerable increase in their importance.

The maximum number of successive rejections allowed is a maximum of 3, in the current implementation, value that avoids erroneous collection of points that do not belong to the vectorized road. The minimum number of rejections is 1.

In the process of vectorization, a large number of vertexes are obtained. For generalization of the obtained vectors, the Douglas-Peucker algorithm is used, and the generalization tolerance is chosen according to the road width. Good results are obtained from the point of view of precision if natural roads are chosen values less than 2 m and for hard roads more values are generally recommended large 2 m (fig. 8a and 8b).

Fig. 8 Generalised (blue) and non-generalised (red) roads: a) end of segment 1 and b) end of segment 6.

Regarding the values obtained for the maximum deviations of the generalized vectors from the road axis, it is noticed that they vary depending on the length of the road profiles (and implicitly the width of the road).

There are cases where one or more final vertexes are not on the road. This is mainly due to the mediation of the previous profile with the profile from the second starting point, a threshold of the lower correlation coefficient and similar radiometry. These minor shortcomings can be corrected manually. Except for these situations, such as the final vertices of segments 1 and 6, which are shown in Fig.8a and 8b), where the error in the end point has not been measured, the other errors do not exceed 2 m, which leads to a very good planimetric accuracy of vectorizations performed.

Another factor to be analyzed is the degree of completeness of vectorization in the sense of semi-automatic collection of all roads visible on orthoimage. This is expressed as the ratio between the actual length of the road or road segment analysed and the length of the semi-automatic vector road segment and it was found to be generally smaller for hard and very large roads for natural roads (8). The main explanation is the presence of various natural or artificial topographic details on the road edges: trees (fig. 9), parked or walking cars, construction, etc. In the case of long strings of trees and shadows the algorithm stops.

If the value of the search step multiplied by the current number of rejections exceeds the size of obstacles on the roads, the algorithm only continues if the next search finds a profile similar to the template profile and the current number of rejections does not exceed the value set maximum.

Generally, in the case of simple intersections, the algorithm continues to vector in the direction closest to the previous orientation. In the case of more complicated intersections where there are other constructions or the road width changes (fig. 8a) the algorithm stops.

Fig. 9 Influence of trees located next to road to vectorization

Fig. 10 Vectorization of a road segment with sinuosities

In the tested area there were no roads with sinuosities, but the algorithm behaves well if their physical characteristics remain unchanged. In Figure 10 is illustrated a case of vectorization of a road with sinuosities. Because in practice the reflectivity of a road is not constant throughout its entire length, it varies depending on the surface material and other topographical details and nearby artificial elements, a complete road can be vectorized successively by using the last vertex determined using the application and indicating the second point. Surely the algorithm proposed by the author can be improved by special treatment in case of rejection. In this case, for example, the last determined valid point can be retained and the orientation from the penultimate two valid points can be used.

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