Road extraction for EuroSDR contest

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ABSTRACT

This paper presents the participation of the SIC to the EuroSDR contest (European Spatial Data Research; formerly known as OEEPE) about road extraction. After presenting the framework of the EuroSDR contest, our approach for road extraction is described. It consists of a line detector based on edge detection using a straightness constraint obtained from geometrical moment to filter out non-straight segments. Those segments are then filtered according to the NDVI (vegetation index) since roads are made of material different from vegetation. Resulting figures about the completeness, correctness and localization precision of the road segments are discussed for the EuroSDR data, and compared to the results of other challengers participating to the contest.

Keywords: EuroSDR contest, line detector, straightness, geometrical moments

1. INTRODUCTION

In the framework of EuroSDR, the project "Automated extraction, refinement, and update of road databases from imagery and other data" [1] aims at the detection of roads in order:

- To survey the data specification needs of important data producers;
- To evaluate the current status of research;
- To test and compare existing semi- or fully automated methods using various data sets and high quality reference data;
- To identify weak points and to propose strategies and methods that lead to a fast implementation of operational procedures for road extraction, update, and refinement.

A contest was setup to compare approaches on the same data set relatively to completeness, correctness and the localization precision of detected roads.

The detection of roads is an important topic of the remote sensing literature, first because of the rather strategic necessity of the communication network and secondly thanks to the large visibility of roads in conventional satellite images for more than 10 years. Major approaches concern the detection of radiometrically uniform and elongated regions [2], the detection of edges with geometrical continuity [3], or voting with image space transform like Hough [4]. Although an adaptation of the algorithms was necessary with the recent very high resolution sensors, the road network has kept its major interest and different clues have been integrated for larger robustness. In the case of Ikonos or Quickbird images, the high resolution multi-spectral bands allow for the vegetation index (NDVI) to be used as an additional filter and roads may be localized thanks to their centers or borders from the detailed panchromatic images.

In this paper, road extraction was achieved by a segment detector including length, straightness and NDVI constraints, as explained in section 2. The motivation and mathematical background for straightness measurement with geometrical moments is detailed in section 3. Section 4 describes the algorithm for edge detection, point linking into segments and segment filtering based on the straightness criterion. Section 5 presents the results in the form of an image superimposed with detected road segments as well as the figures of merit computed by the EuroSDR contest initiative and compared to challenger results. Conclusions are given in section 6.

2. METHODOLOGY

Our approach for road extraction is derived from the observation that roads usually have a rather uniform response spectrum and are often contrasted from their surrounding background. Moreover, their shape is curvilinear and correctly approximated by linear segments. Roads are also made of material well different from vegetation. These spectral and geometrical clues have been used in the following way.

First, the *Bar Detector* [5] was used to highlight bright thin segments. This detector uses the fact that at each side of a valley or crest of image grey values, the gradient vector points in opposite directions. The implementation does not require any parameter setting except the value for Gaussian smoothing and the type of object (valley or crest). The detected bars are made 1-pixel wide thanks to a non-maxima deletion process.

Secondly, linear straight segments were extracted by imposing a minimal contrast and a minimal length while constraining the shape to be straight enough, with the straightness measured as the square root of the principal moment of inertia of segment points (see section 3).

Finally, extracted linear segments received a value based on the NDVI of segment points. The vegetation index value NDVI is obtained from the red (R) and infrared (IR) channels at each pixel by the ratio (IR-R)/(IR+R). If the NDVI average value along a segment was above *MAX_VEGET*, the segment was rejected.

3. STRAIGHTNESS CONSTRAINT

We suggest the use of moment of inertia to measure the straightness of linear segments. Segments are initiated with strong edge elements of the *Bar Detector* (section 2) and enlarged with neighbor edge points looked for in a consistent direction until no connected edge points are found. A candidate segment is left as soon as a straightness measure is not satisfied or if the resulting segment length is too short.

The moment of inertia gives a straightness measure with intuitive interpretation and can be expressed in pixels, when its square root is considered. Its computation is effective, particularly with an incremental algorithm considering only the processing of the last point added to the segment. Also, in the approach given below, the moment of inertia axis is not explicitly and unnecessary computed, although it can be directly derived when needed.

For a set of n points of coordinates (x_i, y_i), the minimum moment of inertia is given by:

$$Mom = \{ Mxx + Myy - sqrt[(Mxx-Myy)^2+4*(Mxy)^2] \} \ / 2 \qquad (1)$$

With

$$Mxx = Sxx / n - (Sx/n)^2$$

$$Mxy = Sxy / n - (Sx/n)*(Sy/n)$$

$$Myy = Syy / n - (Sy/n)^2$$

$$Sx = \sum x_i; \qquad Sy = \sum y_i$$

$$Sxx = \sum x_i * x_i; \qquad Sxy = \sum x_i * y_i; \qquad Syy = \sum y_i * y_i$$

The incremental computing of the moment consists in adapting successively S_x, S_y, S_{xy}, S_{xy}, S_{yy} and M_{xx}, M_{xy}, M_{yy} values due to the new point contribution to obtain the new *Mom* value. This requires a few operations only and is independent on the number of points that the segment already contains. Since the straightness parameter may be seen as a simple distance in pixel when the square root of *Mom* is considered, we compare the obtained *Mom* value to the square of the parameter specified for straightness.

The axis of inertia corresponding to value *Mom* is the best fitting line in the sense of the lowest mean squares (orthogonal regression). This axis passes through the gravity centre ($G_x = S_x/n$ and $G_y = S_y/n$) with a slope:

$$M_{xy} / (Mom - M_{xx}) \qquad (2)$$

4. STRAIGHT-LINE EXTRACTION

Straight linear segments are detected in a two-step procedure. Important visual local cues are first detected as possible road points by an edge detector. Then detected points are linked, ensuring the continuity and straightness of the constructed segments.

4.1 Point detection

To detect road candidate points, we applied the “Bar Detector” of [5] to look for bright lines (crests) with the Gaussian smoothing factor of 1.2. A non-maxima deletion is performed, using the crest local direction. The output is a feature image with gradient orientation and magnitudes with high values where crest lines are likely to be present.

4.2 Point linking

Pixels of the feature image with gradient magnitude higher than threshold *START_GRAD* are candidate as segment seed points. Their gradient orientation constraints the direction for point linking in one of the four direction (Fig. 1a: E, SE, S, SW) for a bottom, left to right scanning. Point linking is realized by stepping to the pixel with maximum gradient among the three 8-neighbor pixels in the direction consistent with the segment orientation.

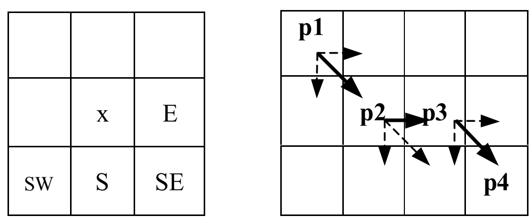

Fig. 1 a) Main search direction and b) point linking.

4.3 Straight-line extraction

From all pixels in the feature image, scanning from top to bottom, left to right, a segment is initiated if the gradient magnitude is superior to *START_GRAD*. The next segment point is one of the three 8-neightbors with maximal gradient magnitude, if the latter is above *MIN_GRAD*. The linking procedure is stopped if the moment of inertia, computed incrementally, exceeds the square of threshold *MAX_INERTIA*.

A segment is rejected if its length is below the threshold *MIN_LENGTH*. To save computations, the constraint on straightness (*MAX_INERTIA*) is checked only when the segment counts as many points as the required minimum length parameter *MIN_LENGTH*.

Acceptable segment points are marked by zeroing the magnitude in the feature image to avoid subsequent detection and segment duplicates. This may result in discontinuities, especially at crosses, but partial segments can be concatenated in a later stage.

5. RESULTS

We applied the presented algorithm for road extraction to the image Ikonos1_sub1 of the EuroSDR contest, the most difficult example of the set of images available from the website of the contest.

5.1 Parameters

According to visible roads in Fig. 2, the "Bar detector" was applied to detect bright points (crests) of the green channel of the pan-sharpened Ikonos image. The Gaussian Lowpass filtering was set low (1.2).

We chose low values for the parameters to initiate and follow a segment (*START_GRAD*=10 and *MIN_GRAD*=4) to ensure that valid segments with low contrast were not rejected. We preferred to be more stringent on the straightness by imposing a maximum value for *MAX_INERTIA* of 1.0, corresponding to a standard deviation of 1 meter perpendicular to the segment direction. This filters most false alarms from natural origins while accepting local deviation and small curvature of road segments. The minimum length (*MIN_LENGTH*) was set to 30, corresponding to 30 meters. The *MAX_VEGET* parameter was set to 0.

Fig. 2: Green channel of image 'ikonos1_sub1' of EuroSDR contest

5.2 Discussion

In Fig. 3, correctly detected road segments are drawn in green, while red is used for missing segments. We observe that many road segments are missing (in red), corresponding to dark, hidden or shadowed parts of roads. But detected segments are mostly confirmed by the ground truth (drawn in green) as depicted in Table 1. Wrongly detected segments, drawn in blue, are typically aligned bright roofs, with a width similar to roads.

Parameters about contrast (*START_GRAD, MIN_GRAD*) and straightness (*MAX_INERTIA*) were roughly estimated and are not critical. The length parameter *MIN_LENGHT* was set manually as a compromise between rejecting spurious edges and keeping short segments. The value for MAX_VEGET as middle range (0) of the vegetation parameter seems appropriate and has not been analyzed further. The automatic adaptation of the parameters to the image under analysis would probably bring little improvement.

No "High-Level" processing like segment linking and segment completion has been applied and would be the major improvement of the approach.

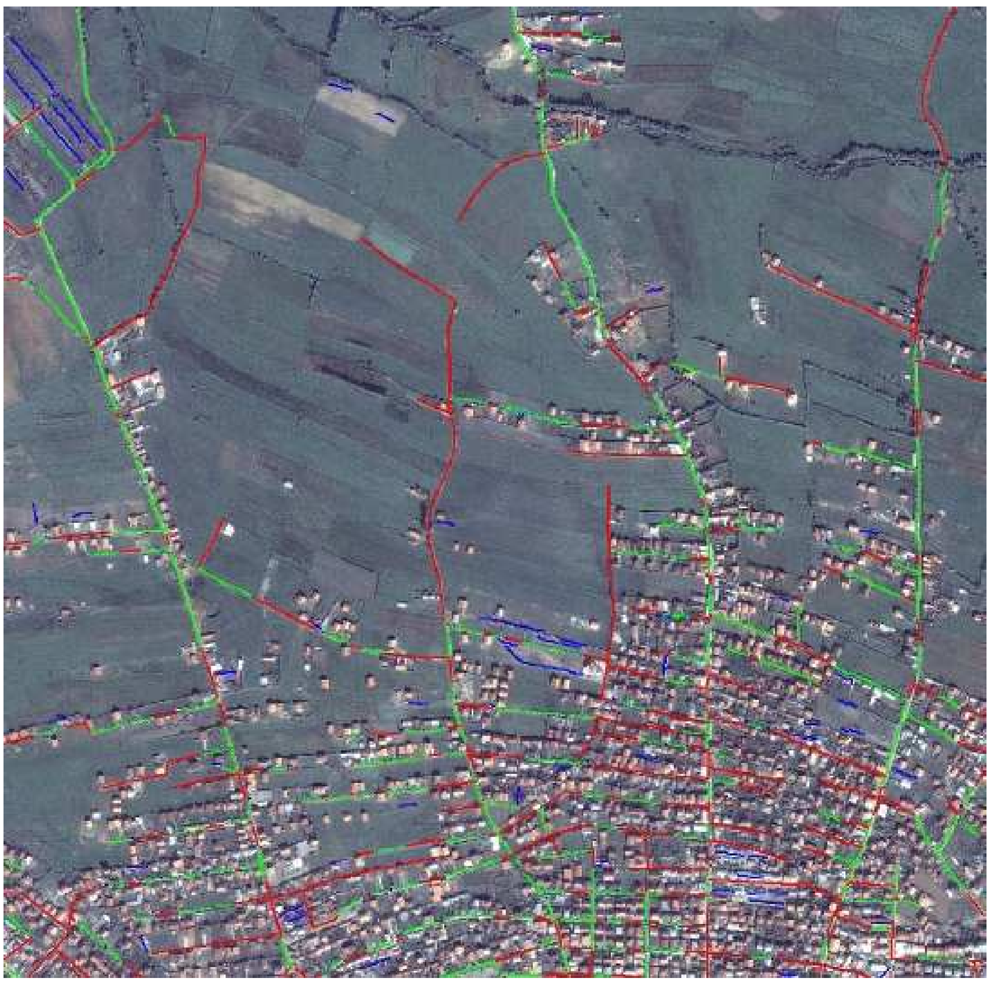

Fig. 3: Extracted roads: Green=correct, Red=missing, Blue=false positive

5.3 Performance indices

Based on ground truth, three performance indices were evaluated by the EuroSDR initiative. The *completeness* (0.48) indicates the percentage of detected segments relatively to the total number of real road segments. The *correctness* (0.69) gives the percentage of correctly detected segments relatively to all the detected segments. *RMS* (1.30), expressed in pixels, gives the precision in localization as the root mean square error between the detected segments and the manually digitized ground truth.

Table 1: Performance figures for image Ikonos1 Sub1

Algorithm	Completeness	Correctness	RMS [pixel]
Bacher	0,34	0,66	1,29
Malpica	0,25	0,74	1,13
Beumier-Lacroix	**0,48**	**0,69**	**1,30**

Our figures compare well relatively to challengers. The completeness figures of all algorithms are quite low due to the complexity of the scene: in the urban areas, many roads suffer from occlusion or shadowing.

6. CONCLUSIONS

A method for road detection has been developed and tested in a unified testbed for objective analysis and comparison. Candidate segments are created at pixels of sufficient gradient and are grown from neighbor pixels in a consistent direction and as long as the gradient and segment straightness are sufficiently strong. The straightness criterion has been implemented by the moment of inertia of segment points, allowing for an effective and fast implementation and intuitive interpretation of the parameter value.

Results are encouraging relatively to the time devoted to development and to challengers's results. The dependence to the parameters is low. The expected major improvements concern the use of higher level processing like line linking and completion and the parameter adaptation to the image under analysis.

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