Straight-Line Detection Using Moment of Inertia

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***Abstract*-Straight-line detection is a basic step of image analysis for many pattern recognition applications, especially when looking for man made objects. Straight line segments are primitives like points or arcs on which to base a higher-level representation for object recognition.**

We propose a novel method for the detection of lines with minimum straightness. It consists of a point linking procedure verifying a straightness constraint measured by the moment of inertia of the segment points. A neighbor point is added to the segment if the enlarged segment has a limited moment of inertia. The implementation was computationally optimized to abandon inappropriate segments as soon as possible and to limit the cost of inertia computation to the current point thanks to an incremental scheme.

The straight-line detection algorithm is general purpose and contains an intuitive straightness parameter expressed in pixel. It was applied to several types of images and is demonstrated here for the detection of roads in satellite images in the framework of the EuroSDR challenge and for the detection of conducting stripes of printed circuit board.

I. INTRODUCTION

In human vision, edges are important cues for object detection as they arise from discontinuities in texture, depth or surface normal. In computer vision, edges are detected by high-pass filters and may be linked to form objects boundaries. The obtained curves can be analyzed to look for specific shapes. Straight segments are basic primitives which are conveniently used for object description, particularly in the case of man-made structures.

Edge detection and line finding have been considered since the early days of computer vision [1]. As outlined in [2], lines are often obtained by a two-step procedure. First edges are detected by a local operator measuring the magnitude of the discontinuity and in many cases its orientation. The edges are then aggregated into curves, using properties like connectivity or linearity.

The literature regarding edge detection is large [1]. The major difficulty consists in solving the compromise between the local sensitivity to fine details of small detectors and the robustness of detectors with larger window of analysis. The edge magnitude is usually used as edge presence likelihood while the edge orientation typically helps edge linking and thinning.

Many techniques have been developed to aggregate local edge information into more global line-like structures. They include for instance the Hough Transforms, contour following and curve fitting.

The Hough Transform (HT) is one of the standard methods and is reviewed in [3]. It consists in accumulating counters in a parameter space based on detected points (typically edges) in the image. Peaks in the parameter space correspond to curve (line) in the image. HT has the advantage to detect lines partially occluded or degraded by noise. First implementations suffered from large memory needs and computation loads as well as inaccuracy and difficulties related to the parameter space. Many research works have been devoted to solving those problems [4]. But the location and straightness of detected segments are not easily available from the Hough analysis and must be analyzed in the image.

Other good reference works are summarized below. Reference [5] presents linear feature extraction through edge detection and thinning followed by edge linking based on proximity and orientation. Linked elements are then approximated by piecewise linear segments. Burns and Hanson [2] make use of edge orientation to locate regions of line support and detect the line as the intersection of the support region with a planar approximation of the edge intensity surface. Then line characteristics such as the length, width, steepness and straightness are estimated. In Reference [6], edge points are assigned a line label based on connectivity during a scan-and-label procedure. Each line label records a set of attributes which allow for a later extension and filtering of detected lines. In Reference [7], constraints on the gradient of neighbor pixels help detecting linear or corner features.

In this paper, we present a novel approach for straight-line detection which involves a straightness criterion using moment of inertia, subject of section II. The straight-line detection algorithm presented in section III is computationally effective. It initiates segments only for strong feature points and enlarged them with connected points looked for in a consistent direction, leaving a candidate segment as soon as the straightness constraint is not satisfied. The application of this straight-line detector is general purpose and is demonstrated in section IV for two different applications: road extraction and stripe detection of printed circuit board. Results are given in section V and conclusions in section VI.

II. STRAIGHTNESS MEASURE

A straight line can be seen as a set of points with a null moment of inertia along its principal axis (the line). The advantages of computing the moment of inertia as straightness measure are that:

- this measure, expressed in pixel, has a physical and intuitive meaning;
- the principal axis of the set of points does not have to be explicitly localized;
- the algorithm can be incremental, adding the contribution of the next candidate point, without the need to consider all the segment points.

The inertia value can be interpreted as the inverse of straightness. A straight line has indeed null inertia. Since the unit for inertia is the square of a distance, we will use as parameter the square root of inertia which relates to a distance (in pixel). Our straightness measure can be interpreted as the standard deviation of the set of segment pixels perpendicularly to the axis of minimal inertia (the approximated straight line).

The moment of inertia can be computed without the direct determination of the principal axis, which reduces computations. This axis can be nonetheless derived, for instance once the segment has been completed, to get the best matching straight line.

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

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

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 incrementing n and 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, independently on the number of points that the segment already contains.

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:

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

III. STRAIGHT-LINE DETECTION

Straight-line detection consists in a two-step procedure. First points are detected to highlight important visual local cues of possible objects. Then points are aggregated by a linking procedure which ensures continuity and global straightness of detected segments.

A. Feature Detection

The choice of a feature detector is not critical as long as an appropriate noise (low-pass) filtering is performed and features are correctly highlighted for the scale of interest. Interesting features may be edges, valleys or ridges, depending on the application.

With the intention to detect the centre of linear segments, more robust than edges, we applied the “Bar Detector” of [7] which looks for valley or crest regions. The approach is based on the fact that, at each side of a crest or valley line, the gradient vectors point in opposite directions. The filtering process does not require any parameter setting except the value of the smoothing Gaussian and the type of object, i.e. ridge or valley. The filtering process generates a crest/valley norm and a discretized direction (0-3) which is locally perpendicular to the local crest/valley direction. In order to obtain a one-pixel wide line detection, a non-maximum deletion is performed, using the discretized direction. The output is a feature image with high values where crests/valleys are likely to be present.

B. Point Linking

Pixels with a gradient magnitude higher than a threshold (START_GRAD) are candidate as segment seed points. Their gradient orientation constrains the direction for point linking in one of the four search directions (Fig. 1a: E, SE, S, SW) for a top to bottom, left to right scanning. The straightness nature of expected line segments indeed ensures the coherence of edge direction along the segment.

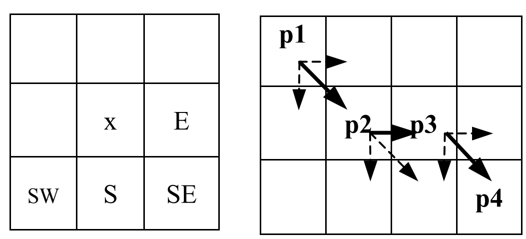

Figure 1 a) Main search direction and b) point linking.

C. Algorithm

For all pixels in the feature image, scanning from left to right and top to bottom, a segment is initiated if the gradient magnitude is superior to threshold START_GRAD. The next point for the segment is one of the three 8-neighbors around the search direction with maximal gradient magnitude.

Point linking is abandoned as soon as one of the following is true:

- The magnitude for the next point is not above threshold MIN_GRAD;
- The image border has been reached;
- The moment of inertia exceeds the threshold MAX_INERTIA.

The segment obtained by point linking is rejected if its length is too short (MIN_LENGTH). To reduce computation load, the constraint on inertia (MAX_INERTIA) is tested only when the segment has the minimum required length. This also ensures that the segment is long enough to reduce the importance of pixel discretization on the straightness estimation.

When a segment is accepted, the ending points or the chain of points are stored, according to the application. Accepted segment points are marked by zeroing the magnitude in the feature image, avoiding subsequent detection of the accepted segment or parts of it. This can result in discontinuities for crossing segments, but edges are often disturbed at crosses and partial segments can easily be concatenated in a later stage.

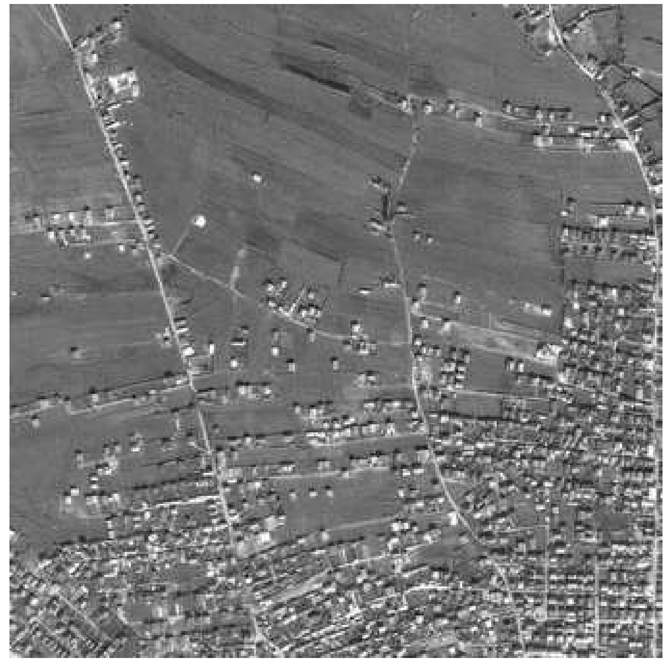

Figure 2: Part of Ikonos1_sub1 image of EuroSDR contest.

IV. Applications

A. Framework

We primarily developed the straight line algorithm for the detection of man-made structures like roads and buildings in aerial or satellite images. In this respect we participated to the road extraction contest organized by the project [8] of the EuroSDR programme, which aims at testing and comparing semi or fully automated methods and which tries to evaluate the current status of research and to identify weak points in road extraction (Fig. 2).

In a later experiment, we applied the algorithm for the detection of straight conducting stripes of a printed circuit board (Fig. 3).

B. Straight-Line Detection

For the EuroSDR contest, according to visible roads of Fig. 2, the gradient line detector of [7] was applied to detect bright lines (crests) on the green component of an Ikonos image (1m of spatial resolution for pan-sharpened spectral bands). Low-pass filtering by Gaussian was set to a low value (1.2). The output is an image with 1-pixel wide points where crests are likely to be present, with gradient magnitude and orientation.

Parameters to initiate and follow a segment were set to low values (START_GRAD=10 and MIN_GRAD=4) to ensure valid segments are not rejected based on contrast considerations. Instead, a MAX_INERTIA value of 1.0, corresponding to a standard deviation of 1.0 meter perpendicular to the segment direction, aims at filtering many false alarms from natural origins while accepting local deviations and a small curvature for road segments. Segments were accepted if they had a minimum length (MIN_LENGTH) of 30, corresponding to road segments longer than 30 m. In this road extraction application, the vegetation index was used as an additional clue to reject linear candidates not corresponding to roads.

In the experiment with printed circuit board, conducting stripes were detected as bright lines (crests) with quite high contrast parameters (START_GRAD=30, MIN_GRAD=20). Due to the particularly straight nature of stripes, the straightness parameter MAX_INERTIA was set to 0.5. The MIN_LENGTH value was set to 8 pixels due to the small image resolution (350 pixels horizontally).

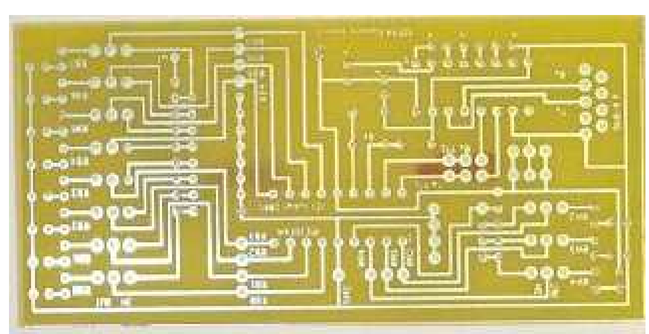

Figure 3: Printed circuit board.

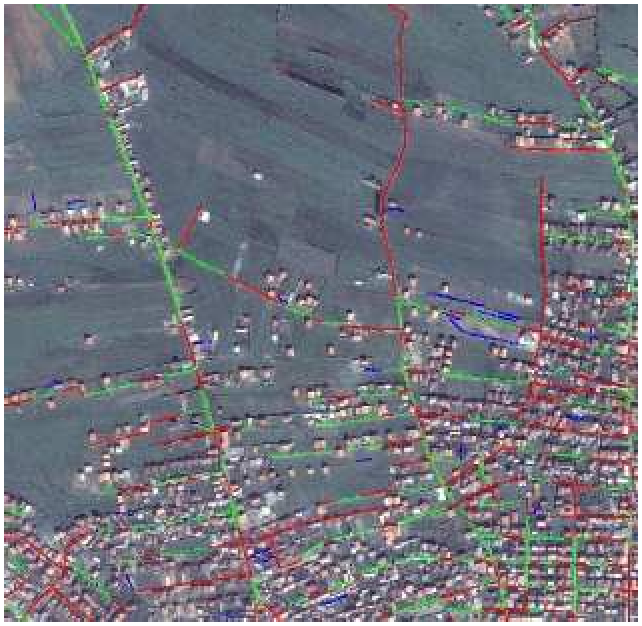

Figure 4: Evaluation results: Green: correct; Red: missing; Blue: false positive.

V. Results

For the road detection application, the algorithm was applied to image ikonos_sub1, the most difficult image of the EuroSDR contest gallery.

Three performance indices were evaluated: completeness, correctness and localization precision. The value of 0.48 for the *completeness* revealed that nearly half of the real road segments have been detected. Among all detected road segments, 69 % related to real roads (*correctness*). The precision of road localization was given as the Root Mean Square error in pixel, 1.30 in our experiment. Those indices were good values compared to challenger algorithms [9] and showed that straightness constraint is a viable criterion for road detection.

Typical false alarms for bright roads are aligned bright roofs with similar width. Many missing road segments correspond to dark, occluded or shadowed roads.

Parameter values concerning the contrast are not critical and could be set automatically from histogram. In this application, the straightness constraint is an important criterion, although many curved segments arise from natural objects and would be probably rejected by the vegetation index constraint.

For the printed board application, detected straight segments are showed in red in Fig. 5. The good image contrast and straightness of the stripes ensured their proper detection. Small errors are due to the low image resolution.

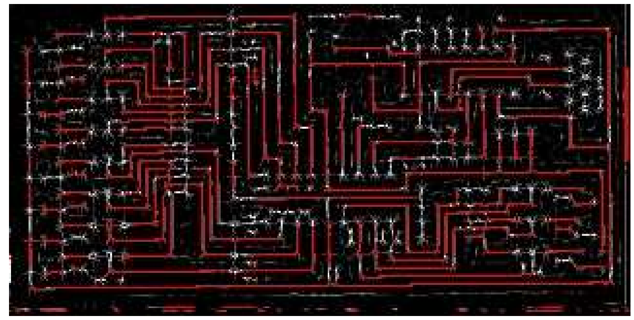

Figure 5: Straight segments detection for the circuit printed board.

VI. Conclusions

A novel approach for straight line detection has been presented. Candidate segments are created at pixels of sufficient gradient magnitude and are grown from neighbor pixels in consistent directions and as long as the gradient and the segment straightness are sufficiently strong. The straightness criterion has been implemented by the moment of inertia of segment points, which allows for an intuitive interpretation of straightness values and a computationally effective implementation based on an incremental estimation of the inertia during point concatenation.

The algorithm has been evaluated for the detection of conducting stripes of printed circuit board and for the EuroSDR contest about road extraction. The straightness constraint appeared in both cases to be an important clue for segment filtering.

Acknowledgment

This research has been supported by the Belgian Ministry of Defense.

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