ROBUST COMPUTER IMAGE ANALYSIS FOR FLIGHT VEHICLES NAVIGATION AND GUIDANCE

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Abstract: The paper is devoted to consideration and development of methods of feature extraction on the images for flight vehicle navigation and guidance purpose. The problem of reliable feature extraction is generally discussed. The types of possible features are listed, their characteristics and requirements are outlined. The new robust method for linear feature extraction is described based on the original algorithm of fast recurrent Hough transform in a sliding window. It is a two-pass voting procedure (by columns and by rows) with the use of special Natural parameterization of straight lines. It is proved that this procedure of lineament extraction is described as a specific morphological "opening" operator.

Keywords: Navigation, Automated guided vehicles, Image processing.

1. INTRODUCTION

The problem of navigation and guidance of flight vehicles, and also the problem of self-orientation of mobile robots in conditions of high variability of 2D information fields produce the requirement of robust detection of some intensity-geometrical image elements called the "characteristic features" or *features*. Thus it is possible to consider the set of representative image features as a navigational field of reference points to be the basis of any constructing algorithms for navigation and self-orientation. This paper is devoted to consideration and development of methods of image feature extraction for navigation and guidance of flight vehicles.

The paper has a following structure.

In the second section the problem of feature extraction is generally addressed. The types of features are listed, their characteristics and requirements are outlined.

In the third section the new method for linear feature extraction is described based on the original algorithm of fast recurrent Hough transform in a sliding window. The connection between this method for lineament extraction and Serra's formalism of Mathematical Morphology is considered.

2. FEATURE EXTRACTION PROBLEM

Due to the high importance of characteristic features for development of object detection and scene matching algorithms, the exploration of different types of such features were performed for typical airborne imagery of real terrain.

Following types of features may appear on the airborne imagery:
- *Points* - corners, junctions of lines, points of high curvature, mass centers for regions or objects, ends of lines, extreme points for some statistics;
- *Lines* - segments of straight lines (lineaments), circular arcs, curved lines, edges of regions;
- *Regions* - connected regions of homogeneous points (by intensity or other statistics), specific shapes (ellipses, rectangles, etc.);
- *Structures* - different combinations of features.

Image features can have a lot of extra characteristics also called “attributes” which allow using different image analysis techniques and methods for additional feature evaluation and selection. The set of image feature attributes can be briefly described as follows:
1. *Location:* Ends of segment, center of segment, mass center of region, vertices of polygons;
2. *Geometric* attributes: Orientation, length, curvature, area, perimeter, width, minimal and maximal diameter of region, axes of symmetry, number and location of characteristic points, compactness, format, etc.;
3. *Radiometric* attributes: Contrast of region, different intensity statistics, sign and the contrast of edge, autocorrelation;
4. *Texture* attributes: Cooccurrence matrix, homogeneity index, energy, entropy, statistics of texture gradients, texture filters results, moments;
5. *Topologic* attributes: Connectivity, neighborhood, common points, intersection, parallelism, overlapping, inclusion;
6. *Color/multizonal* attributes: attribute vectors for each color/zonal channel;
7. *Dynamic* attributes: attributes of static and moving objects;
8. *Temporal* attributes: attributes as functions of time.

The choice of concrete features and their attributes for construction of detection algorithms should base on following criteria, taking into account some special requirements to be of use for navigation field construction:
1. *Presence/Density*: presence of features in all sample images, sufficient density of features for region of interest;
2. *Rarity/Uniqueness*: rarity of concrete feature among the other images, uniqueness of feature in neighborhood;
3. *Invariance/Stability*: robustness in relation to geometrical and radiometric distortions, insensitivity to noise;
4. *Localizing:* possibility of fast localizing;
5. *Interpretation:* possibility of fast recognition and interpretation;
6. *Computation speed: average time of detection of given class of features.*

In operation with real imagery these features possess contradictory properties. Therefore concrete selection of features and their attributes depends on accessible computational power and minimal required robustness of the descriptive features. The "quality" of different characteristics features are outlined in Table 1.

Table 1. The quality of features.

Features	Quality (from high to low quality→)		
Presence/ Density	points	lines	regions
Uniqueness	regions	lines	points
Invariance	points	lines	regions
Noise resistance	regions	lines	points
Localizing	points, (corners, centers)	lines	regions
Interpretation	junctions, closed contours, closed regions	end points, opened contours, opened regions	special points, mass centers
Computational speed	points	lines	regions
Influence of breaks	points	lines	regions
Influence of overlapping	regions	lines	points

This table demonstrates the inconsistency of different features under different criteria of estimation. Therefore in practice it is necessary to investigate and combine different features (points, lines, areas, structures) from the viewpoint of their usage in navigation and guidance of flight vehicles.

3. NEW ROBUST TECHNIQUE FOR LINEAMENT FEATURES EXTRACTION

It is well-known that airborne scenes used for navigation and guidance of flight vehicles at terminal phases of a pathway, as a rule, contain a significant amount of anthropogenic objects.
Similar situation appears in case of self-orientation problem for navigation of mobile robots in industrial outdoor or indoor urban environment. Let's note that in both cases due to high variability of image brightness (due to different conditions of

illumination, day and night, shades, etc.), contour models are much more robust relative to models based on the half-tone samples.

Thus, the problem of robust extraction of straight-line lineaments goes to the foreground, and lineament field could be often used as appropriate basic navigation field. For decision of this problem the new method based on the original algorithm of fast recurrent Hough transform in a sliding window is proposed in this paper.

The classic Hough Transform (HT) is one of the most popular image processing procedures those of use for linear object extraction. It is well known that HT is a global image processing technique, but feature extraction operators are usually imagined as local procedures those provide the detection of local objects and filtering of local features. The usual way to avoid this problem is to separate the image onto smaller parts and apply HT to these parts, but this way gives problems at the edges. So, we need to make HT for the neighborhood of each point, but iterative HT in the sliding window is too expensive in the computational sense.

To solve this task, the new implementation of Hough procedure – *Recurrent Hough Transform* in a sliding window (RHT) was developed. It is the two-pass procedure of recurrent voting of contour pixels from sliding window into the special accumulator. The accumulator has different parameterization for each pass: (x,fi1) for row pass and (y,fi2) for column pass correspondingly, where {fi1} and {fi2} – separated parts of common angular space. This allows directly representing current shifts of processing window by corresponding shifts of special accumulators. Since both passes done, the accumulator contains for each point of image the best angular direction and the number of votes for this line segment.

It is shown that for window size N and some threshold K the result of accumulator thresholding has the properties of (K/N) rank filtering of source contour image with rotating line-shape window. If K=N, this procedure could be considered as a morphological erosion. Moreover, we can define the corresponding image restoration operation that creates the corresponding morphological opening for this erosion.

Let's define the following order of operations:

1. Perform the RHT.
2. Binarize the RHT-accumulator with some threshold value THR.
3. Eliminate all image points, such that their response in binarized RHT-accumulator does not contain non-zero points.

This operator is:

- decreasing;
- inclusion preserving;
- algebraic projector,

i.e. it satisfies all conditions of Serra's morphological filter (Serra, 1982). This proposition can be easily proved in the formalism of the *monotonous morphology* proposed by authors earlier (Visilter, 2000; Visilter, 2002).

The *monotonous morphology* is a morphological technique based on the following set of operators:

- E(Im): IM→ACC.
- M(Acc):ACC→ACC, M(Acc)<=Acc.
- D(Acc): ACC→IM, D(Acc)<=Im,

where IM – image space, ACC – Hough space (for HT, GHT or RHT), "→" – space-to-space mapping notation, "<=" – "*not greater image*" relation of partial order means that from {Im1<=Im2} follows {Im1(x,y)≤Im2(x,y)} for each point (x,y). In this scheme E(Im) operator is called "voting" or "*image deconstruction*"; M(Acc) operator is called "accumulator analysis" or "*accumulator erosion*"; D(Acc) operator is called "*image reconstruction*" or "*dilation*". Note that in difference with classic Serra's MM, the ACC space should not have a sense of image space like IM. ACC may have the other geometry. So, E and D operators are not the monotonous image operators any more. However, their combination – "monotonous opening"

- O(Im)=D(E(Im)),

has all features of Serra's morphology opening filter: O(Im)<=Im; O(O(Im))= O(Im).
Let's prove the following proposition.

<u>Proposition 1</u>. Let M(Acc) is an operation of local maxima extraction with the Acc value greater than some threshold. These maxima will be breserved, but all other points of Acc filled by zero value. And let O(Im) deletes all points of source image voting to zero values of M(Acc) only. *Then any Hough-like voting procedure implementing the fusion of homogeneous evidences for geometric hypothesis can be considered as a monotonous opening.*

<u>Proof.</u> At first, O(Im)<=Im by construction, because it may delete some points of source image but does not create any new points. So, we need to prove the condition O(O(Im))=O(Im) only. Let's do it from the converse assumption.

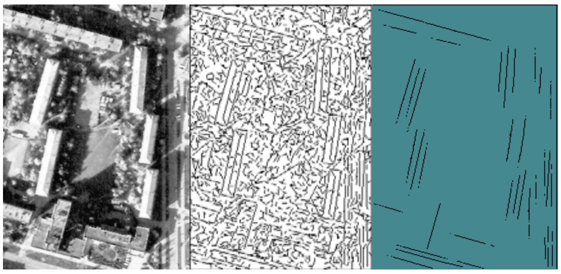
Let's assume that O(O(Im))>O(Im). It means that there will be at least one new local maximum in O(O(Im)) relative to O(Im). So, we need to assume some new points in O(Im) producing this maximum those were not in Im. However, this assumption contradicts to O(Im)<=Im.

Then let's assume that O(O(Im))<O(Im). It means that at least one local maximum will not be in O(O(Im)) relative to O(Im). So, we need to assume

some image points voting to this maximum to be deleted in O(Im). However, it is impossible by construction (defenition) of O(Im). Thus, O(O(Im))=O(Im), q.e.d.

The *conclusion* from this Proposition 1 is that the RHT procedure for lineament extraction will be the Serra's morphological opening operator too. Such procedure of *RHT-opening* has the following sense: preserve all points of source image those vote into non-zero points of eroded accumulator. It is just equivalent to the disjunction of usual morphological openings with differently rotated line-shape structuring elements.

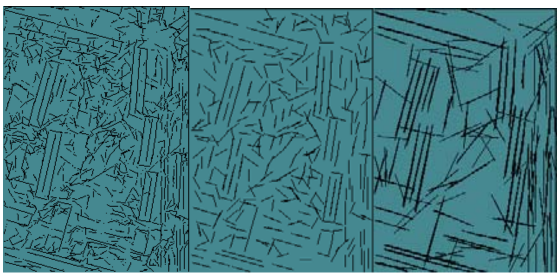
Fig.1 demonstrates the steps of lineament extraction by Recurrent Hough Transform in a sliding window.



(a) *(b)* *(c)*

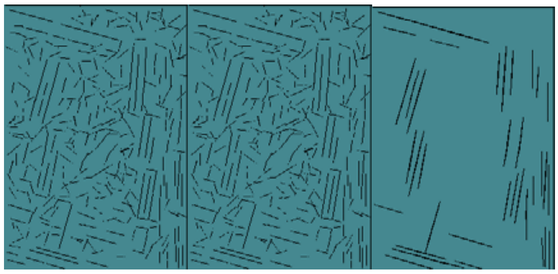
Fig.1. An example of Recurrent Hough Transform in a sliding window (a) – source image; (b) – binary contour image; (c) - result of RHT-opening. Lineaments are selected.

Figures 2,3 demonstrate results of RHT-rank filtering and RHT-opening with different parameters of window size and rank value for contour map for air born image of Ufa city. These examples demonstrate the possibility of RHT-rank filtering and RHT-morphological opening for extraction of lineaments for automatic building segmentation.



(a) *(b)* *(c)*

Fig.2. An example of RHT-rank filtering with different parameters of window size (a) – small window size; (b) – medium window size; (c) - large window size. Lineaments are selected.



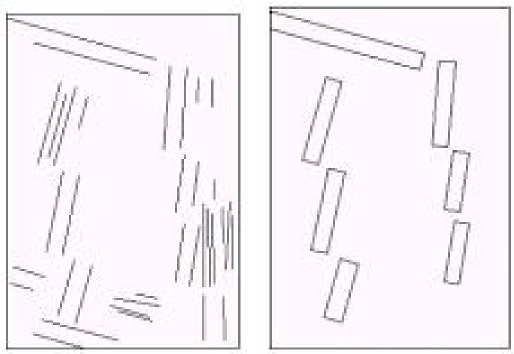
(a) *(b)* *(c)*

Fig.3. An example of RHT-morphological opening with different parameters of window size (a) – small window size; (b) – medium window size; (c) - large window size. Lineaments are selected.

Let's consider the problem of detection/matching of binding or other simple artificial objects as an example of further usage of extracted set of lineaments.

The result of described algorithm for lineament extraction can be represented as a list of linear segments with their attributes. With the help of these attributes some further relations between lines can be formed: proximity, parallelism, perpendicularity, etc. Based on these relations some simple structures can be formed: parallel pairs of segments, rectangles (see. Fig.4a). These structures are the important characteristics of artificial objects (building, roads and so on).

Fig.4. demonstrates the extraction of geometrical structures for building detection/matching for the same typical urban scene on airborne imagery. As seen from the picture, the model of scene structure is obtained that allows practical usage for navigation and guidance of flight vehicles based on the cartographic and other available information about the downstairs terrain.



(a) (b)

Fig.4. Extraction of geometrical structures for building detection/matching. (a) Parallel pairs; (b) Rectangles.

4. CONCLUSIONS

The paper is devoted to consideration and development of methods of feature extraction on the images for navigation and guidance of flight vehicles.

The problem of feature extraction is generally considered. The types of features are listed, their characteristics and requirements are outlined. Properties of these characteristic features are ordered depending on the "quality" on some different criteria.

The new method for linear feature extraction is described based on the original algorithm of fast recurrent Hough transform in a sliding window. It is a two-pass voting procedure (by columns and by rows) with the use of special Natural parametrization of straight lines that allows implementing Hough transform in a sliding window as an efficient computational procedure due to recurrent renovation of accumulator array at each position of window in a pass. It is also demonstrated that this procedure of lineament extraction can be described as a specific Serra's morphological "opening" operator.

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