KNOWLEDGE BASED SYSTEM FOR THE AUTOMATIC EXTRACTION OF ROAD INTERSECTIONS FROM AERIAL IMAGES

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ABSTRACT

A National Geographic Agency is a mapmaker and a database producer. The current manual stereoplotting of cartographic objects is time consuming. To reduce this production cost, we are working on problems related to the photogrammetric data capture automation. Based on our experience of road network systems and on our cartographic requirements, we consider road intersection extraction as a specific problem. In this article, the complete architecture of our system is presented in three steps: a specific intersection model description, the interpretation strategy and a decision-making process. We detail the simple intersection and roundabout process and evaluate the system behaviour on a large set of data.

1 INTRODUCTION

The need of accurate topographic databases is increasing and specially, in road network. In order to help and reduce the manual stereoplotting, we are looking for methods based on automatic image interpretation system. The analysis of 1:30.000 aerial images (0.5m of ground pixel resolution) requires a complex reasoning due to the inherent complexity of images and of man made objects. A hierarchic approach is proposed using a low-resolution external database (~10m). Starting with this external database, a single intersection is chosen to focus our attention on an image area, to drive the extraction of features and fashion a high-resolution intersection (~0.5m) with a refined description. This final description might respect the cartographic requirements: readability and accuracy. The external database is a right information, up to date and we will not doing any change detection between the two descriptions. Another objective is to demonstrate through the state of the art in road extraction, the necessity to propose a dedicated intersection extraction.

Most existing methods first focus on road extraction to create the road network. Then, the extraction of road intersections is usually realized by perceptual grouping on road hypotheses. On that account, their local behaviour depends on road geometric quality and a small planimetric mistake can introduce a large modification of intersection shape. Beside, the existence of typical structures in the centre of the intersection poses a problem to the perceptual grouping. Groch (1982) and De Gunst (1994) use a road following method and detect intersections when the road width changes enough. Ruskoné (1996) proposes a method based on correlation of concentric radiometric profiles and Baumgartner (1997) based his approach on surface homogeneity in a multi-resolution approach. These different methods are very sensitive to a short edge interruption, to non-parallelism of road edges or to heterogeneity of road surface (cars, road paintings and physical separators). The different conclusions established that road network extraction quality could be improved in the intersection areas. De Gunst (1994) is detecting important changes like a new motorway intersection and a dedicated intersection model is designed on road marking or ground painting.

Our method collects general information in the external database, to draw up a simple intersection model. This model guides the feature extraction to refine this model and proposes an accurate topographic intersection. The image processing extracts a list of possible features attributed by quality assignment (realism) to initiate a decision-making process. The strategy is described for the whole system and a large set of data allows us to evaluate the system behaviour.

2 THREE DIFFERENT INTERSECTION MODELS

The complex reasoning, to extract information in aerial images, requires external knowledge. In our approach, a database is used to propose an intersection classification with four main intersection classes: simple intersections, roundabouts, complex intersections and highway intersections. Then, the image analysis has to complete this basic model and draw an image description of the intersection. The cartographic model is an interpretation of the image model (a generalization) to respect cartographic requirements. Each intersection is composed by different objects distributed in three levels described in the figure 1. These different objects are connected through a semantic network including the composition relations (*is composed by*) and the dependency relations (*is followed by, is connected to…)*.

2.1 A basic intersection description

The external database is composed by geometric and semantic information. The geometry provides us approximate node localization and road directions. The semantic is composed of different attributes about approximate road width, hypothetical number of ways, administrative classification … A previous analysis based on production rules provides a basic description for each intersection that can be found in the external database. For example, it is interesting to notice the existence of a main road to project the secondary roads and make a good cartographic interpretation. A main road is depending on the local geometry and on possible semantic relations between two road hypotheses. The motorway and the circular road are introduced to describe roundabouts and motorway intersections. These different objets composed the high level of description, which is based on intermediate level objects: roads and surfaces (to describe the market places). An intersection has planimetric coordinates and different attributes on the possible existence of obvious forms. The main road, the motorways and the roads are representing arcs of our road network graph.

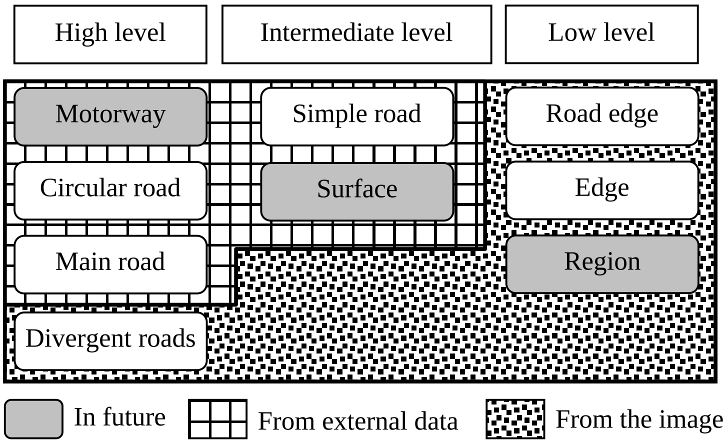

Figure 1: Generic model of road intersection based on the external data and the image.

2.2 A complex image model

The image intersection description is based on the basic model and generally, the shape is not modified (number of roads and existence obvious form). Our problem is to detect the existence of particular object like circles, to reposition the basic model in the image, to extract some features or to make an interpretation of features. Each action is guided by the basic model and by heuristics. These heuristics are based on the construction specifications of roads and set up the accuracy of our image model. All the image models objects are described by contours except the central surface intersection described by a region. Some objects are image instances of basic model objects like roads or main roads. These objects have to be repositioned in the image and different attributes are set up with image processing. It is important to notice that a road hypothesis is assimilated to a homogeneous ribbon. The main road or the motorway are the upper road objects and are composition of different roads (continuity or parallelism). A road circle in the image represents the circular road axis in roundabouts and is described by a centre and a radius. Other objects are extracted from the image or by grouping processes. The angular road is focused on the arrival of roads into the intersection. Sometimes, the lanes are divided to force drivers to take a direction.

2.3 A cartographic model

The image model proposes a very detailed and accurate description of the image reality. In a cartographic process, this model is not clear enough to be drawn on a map and a generalization is necessary (see figure 2). In a manual process, the generalization is made during the stereoplotting. The operator uses database specifications and his own judgement to describe the image in the best way. This step is not considered in our system because this stage might be introduced as a vector simplification, which is not an image understanding problem.

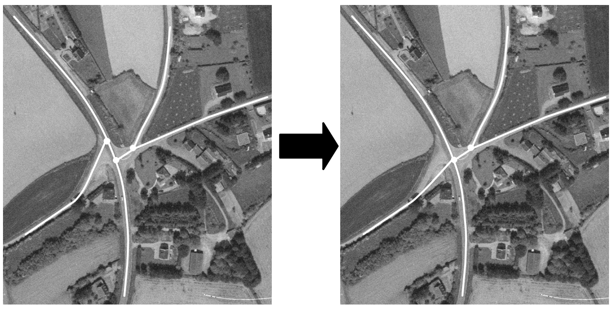

Figure 2: Generalization of an image description into a cartographic model

3 A TOP DOWN INTERPRETATION STRATEGY

A rule-based system analyses each intersection of the external database to set some of the intersection components. Rules describe the external data information and the knowledge used by an expert to draw up an upper intersection description. These rules make reasoning on local road orientation to propose possible intersection shape and consider the global linearity of the road, to estimate the optimal direction. These informations are used in an adaptable focus process to focus attention on interesting areas and set up the image area sizes.

A decomposition tree structures the final database in four main intersection classes: simple intersections, roundabouts, complex intersections (market places), and motorway intersections. A simple intersection has a maximum of five roads. A roundabout is a circular road with connected roads and often, divergent road connections. The final intersection class is the motorway intersection to consider the complex intersection between one or two motorway and roads or main roads. Each class corresponds to a specific process. Beside, a local circle detector is necessary to confirm the homogeneity of classes between a simple intersection proposed by the external database and the image reality.

A global intersection decision-making has to accept or reject the list of intersection and save the best solution in a final list. This complex mechanism is based on a systematic estimation of the confidence in a feature. This confidence is called here realism to make a difference with the quality evaluation of a result with a reference. The accepted intersection has a high level of details and a generalization is necessary to respect the final specifications of the topographic database.

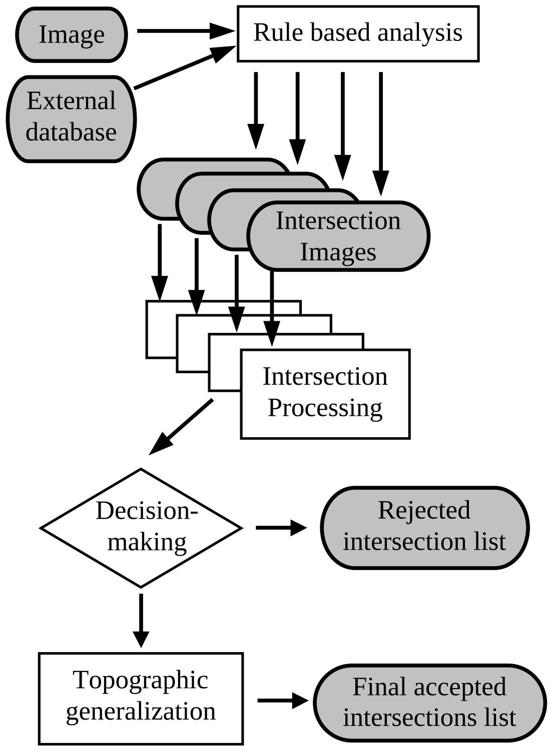

Figure 3: A top down strategy for automatic road intersection extraction

3.1 The intersection realism

The auto-evaluation process is specific to each object level with a realism attribute to measure the “image quality”. This realism will be evaluated during the object creation process and depends on the lower object realism. Fusion functions are combining geometric and radiometric measurements to propose a unique realism. This realism is computed with different quality measurements estimated through fuzzy functions. These fuzzy functions are parameterized with a large set of data (~100 images). The variability of image quality and the selection of good hypotheses allow us to identify the efficient function which means that the good solution is always present in our list of hypotheses. The fusion between different elementary realism proposes global trust estimation in each complex feature then in our intersection.

The elementary realisms are calculated by comparison of the extracted feature and the corresponding edges. Beside, a good road edges is based on a long, contrasted and smooth curvature polyline model. Then, to estimate the realism of a road or a circular road, geometric and radiometric informations has to be introduced. The road geometric measure is based on the parallel grouping of two local road edges. The road radiometric measure is based on the local homogeneity of the ribbon and on the edge contrast.

3.2 The decision-making process

This process is very complex because it involves a judgement on exactitude and accuracy of information. The decision-making is based on the previous realism measures and it has to propose a dedicated action. The possible problems are often due to the image quality (contrast or heterogeneity), to the viewing angle (introduce occlusions), to the date and time of the flight (shadows), to the context (cars and trees) and/or to the inadequacy of the model (linear road model on a curve road reality). In case

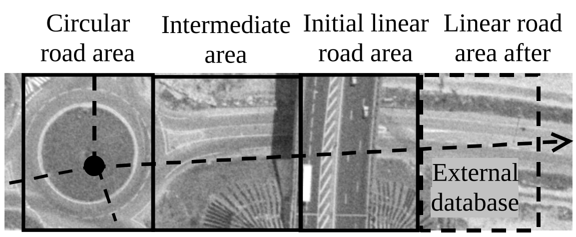

Figure 4: The sub-images for a road extraction process and occlusion for road linear extraction

of failure (none hypotheses is proposed), we focus our image on another area. We present on figure 4 an example of the necessity to move. The move may be proposed if the reason is clearly due to parallel edges grouping, width or radiometric problems. On the other hand, when there are no edges in the external database direction, an image extension is proposed. Beside, too many moves or extensions may introduce reconstruction problems. Then, after some iteration, the system indicates that this area is problematic and keeps the external database proposition.

4 THE SIMPLE INTERSECTION EXAMPLE

These results may present the system originality and the different image processing. In section 3, the top down strategy introduced, for each intersection class, a dedicated and autonomous process. These processes take a “sub-image” and give out a list of attributed solutions ordered with a realism measure. The example of simple intersection needs to reposition each road, then reconstruct the main road before connecting the different secondary roads. The repositioning introduce a local linearity of the road out of the central intersection area.

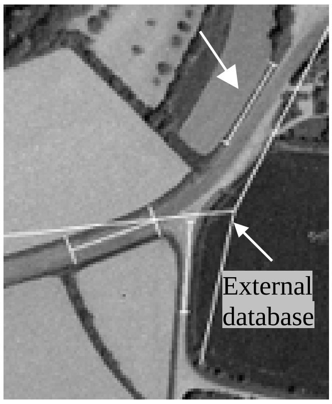

Figure 5: repositioning of each linear road

4.1 The linear road extraction

This process is developed in Boichis (1998) and is based on a Hough (1962) transform to detect linearity. The features are ordered with a realism measure and grouped with a parallel constraint to create a linear road. The figure 5 shows that the best solution is not systematically describing the road because of a local ambiguity. The road hypothesis should be pulled out of the list during the reconstruction (see paragraph 4.2). The performance of this process has been evaluated on a set of 110 heterogeneous images in radiometry and in structures (urban and rural areas). The results inform us that the road hypothesis is present in our list in 78.8%. Beside, the best solution is the road in 56.5%. This result informs us that it is difficult to pull up the road because of an excessive over-detection. The parallelism problem (3.4%) represents the limit of our ribbon road model and demonstrates the necessity to introduce each way to describe the road as a couple of parallel ways. Beside, 23.5% problems are due to the inadequacy of the linear model in the image reality. The others problems are related to the lack of contrast in some images (the road edge gradient is under 15).

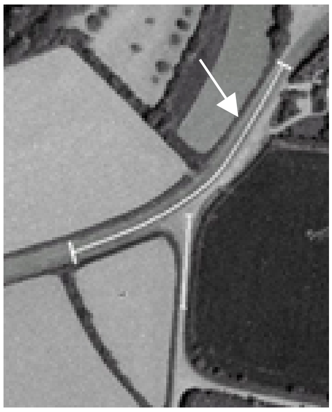

Figure 6: reconstruction of the main road

4.2 The main road reconstruction

The main road is proposed by the rule-based analysis of the external database. Each couple of linear roads is considered and the geometric reconstruction is based on a spline algorithm interpolation. The list of main roads is organized with their realism depending on geometric and radiometric continuity from one side of the intersection to the other. The figure 6 illustrates the changing between the previous local extraction (see figure 5) and the selected linear road after the main road reconstruction. The final list of main roads is composed by different kind of parallel ribbon (the road, the roadside…) and the roadside could be better placed in the list than the road. Nevertheless, we observe, in rural area, the main road is always in the list if the linear road is present. Beside, the best solution is the road in 80%.

Figure 7: reconstruction of a simple intersection

4.3 The intersection reconstruction

The geometric reconstruction of a simple intersection is using a simple extension of each linear road hypotheses (see figure 7). But some complex intersections are composed of three secondary roads. Then, two of them might intersect each other before the main road. In such a case, this intersection is projected on the main road. This reconstruction introduces radiometric homogeneity of roads composing the intersection. As the figure 7 shows, this criterion has to be weakly constraint because the road appearance might be very different in a same intersection. For that reason, the intersection is well described when the best main road and the linear secondary roads are separately good or not very different.

5 THE ROUNDABOUT EXAMPLE

The strategy used to extract the correct roundabout description is based on the same principles as the simple intersection of the section 4. We drive the process with the external database and focus our attention on different areas corresponding to specific objects (see section 2). To activate this roundabout process, a previous detector has to certify the presence of a circle form. If the answer is positive, the circular road has to be extracted to replace precisely the centre of the basic description. Then, the different roads are repositioned before the extraction of each divergent road.

5.1 The circle detector

In the external database, the description of a simple intersection and of a small roundabout are similar. In order to identify this difference as soon as possible, this detector is looking for concentric circles. The circle algorithm is based on a classic Hough (1962) transform extended by Duda (1972) and Kimme (1975) to parametric curves as circles. The existence of one roundabout in our image and the systematic concentricity of circles allow us to focus our attention on the centre identification before to estimate the radius of each concentric circle. Beside, the detection goal is not synonymous of accuracy which justify to work on lower resolution images (~1m). Then, the edge detector of Deriche (1987), combine to a polygonization process, provides a list of edge polygons. Then, all the triple points of each circle polygons will vote for the same centre. A research of “characteristic” accumulation will identify the different centres. For each centre, the process is repeated to estimate the different radius. Then, each circle is qualified by a trust measure (realism). The matching of the circle feature with the corresponding edges estimates the geometric quality of the extraction. Moreover, a radiometric measure defines the adequacy between the circle and the road model. The final realism is a fusion of these measures and sort out the circular road hypotheses.

An evaluation was done on a set of 449 intersections including 16 roundabouts. The first goal might be reliability, then, the realism threshold is set in sort of few simple intersection are considered as roundabouts. For that intersection sample : 4 simple intersections are considered as roundabouts and 8 for the opposite. Such a situation is necessarily complex because 8 roundabouts have to be found in 429 simple intersection. Then, we consider that it is much more interesting to choose an exhaustiveness goal by decreasing the realism threshold. In that case, 14 roundabouts are identified correctly and 27 simple intersections are classified as roundabouts. One of the missing roundabouts is presented in figure 8 to illustrate the robustness of this detector.

Figure 8: example of a misdetected roundabout

5.2 The circular road extraction

To the contrary of a detector, the goal of an extraction process is the accuracy. To that point of view, it is useless to resample the image at full resolution and to introduce more efficient, but time consuming, calculations in the final realism. Thresholds are also adjusted to minimize “good“ solution suppression. The rest of the extraction process is completely similar and the details are developed in the previous paragraph. We applied this process on the 41 roundabouts proposed by the detector and the 27 simple intersection images were eliminated.
Another evaluation on a set of 50 roundabout images show that the right centre was founded in 91%, but in 11% the radius was too small to describe a roundabout and in 14%, the best hypothesis is not the circular road (see figure 9). This kind of ambiguity will be corrected during the global roundabout reconstruction. An example of a correct extraction is proposed in figure 11.1.

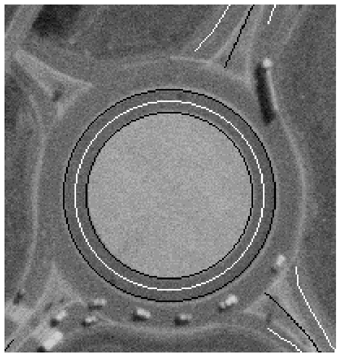

Figure 9: local ambiguity due to the presence of concentric circles

5.3 The linear road extraction

This process has to follow the circular road extraction and reposition each incoming road out of the roundabout centre. A linear approximation is done locally and the process is the same as described in the paragraph 4.1. In the figure 11.2, the best hypothesis of the list for each incoming road, is the “good” road description. This example is not a generality therefore one linear road may be locally delocalized. In such situation, the reconstruction of the branch will correct this local ambiguity. An intermediate description of this intersection is proposed and needs to consider the interpolation between the linear road to the circle centre. A spline algorithm has been retained in order to fit as much as possible the final curvature of each incoming road. The next step in the roundabout extraction process is focused on the intermediate area between the external circular roadside and the linear road. The intermediate image is resample with the interpolation direction.

5.4 The divergent roads extraction

This feature is very complex and unusual because of its shape, its size, its homogeneity and its contrast. The problem to solve is about the detection of divergence between the incoming and the outgoing roads. The idea of this process is based on the local geometric divergence and the radiometric symmetry between each road couple. The first step is the extraction of the existing ribbon in the intermediate image. To solve this problem, we choose an algorithm developed in the laboratory by Guigues (2000) and based on the analogy to light propagation in a wave guide. Each ribbon is associated to a realism measure to qualify the adequacy to our road model. Then, a median axis is calculated for each road couple with a morphological algorithm and the distance to the roads is estimated for each axis points. The divergence estimation is modelled by two lines as represented in the figure 10. To complete this geometric characteristic, a property of radiometric symmetry is considered. The estimation introduces a correlation coefficient between each slice of the left and right images separated by the median axis (see figure 10). The final list of possible divergent roads is qualified with a realism measure by using the width and the radiometric symmetry between these two roads. We evaluate on the 110 intermediate images that 83.6% of them are containing a physical separator. We found that 100% of the non-divergent roads (or classic ribbon) were detected and 64.2% of the divergent roads are extracted. The rest of misdetections are generally linked to the urban context or to a exceptional complexity of the image. In such areas, the presence of cars or road markings disturbs the ribbon extraction and the radiometric symmetry.

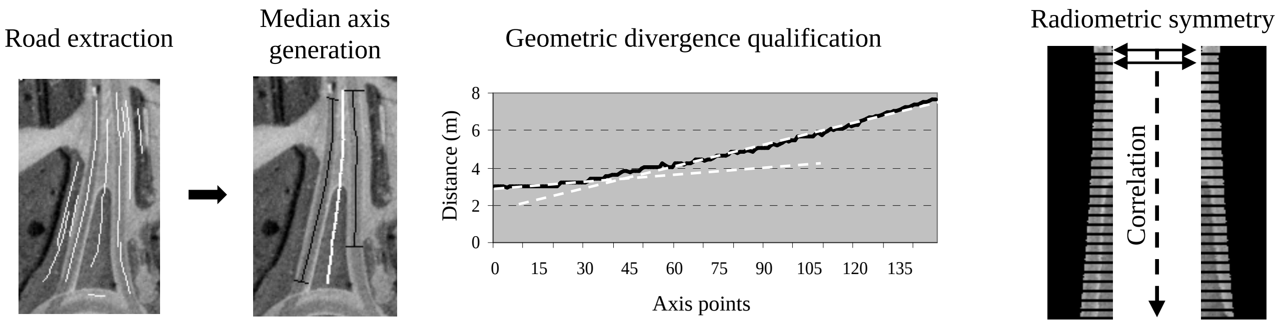

Figure 10: Geometric divergence identification for a couple of roads and radiometric symmetry estimation by a correlation measure.

5.5 The roundabout reconstruction

We have three ordered lists of linear, circular and divergent roads. Now, our problem is to use the composition relations and the dependency relations to connect the correct objects. These connections imply the introduction of geometric and radiometric continuities. The goal of the reconstruction is, first of all, to pull up the “good” solution and second of all, to propose a complete description of the roundabout. We introduce also the credibility in the extraction processes to sequence the filtering. We consider that the linear road list is not very reliable because of the local ambiguity. In order to reduce this effect, the connection with the divergent roads into a branch has to be computed at first. At the end, the connection to the circular road proposes a complete description of the roundabout. The figure 11.1 presents the circular road extraction preceding the linear and divergent road extraction (figure 11.2 and 11.3). The final step (figure 11.4) illustrates the geometric reconstruction and the adjustment of each local solution.

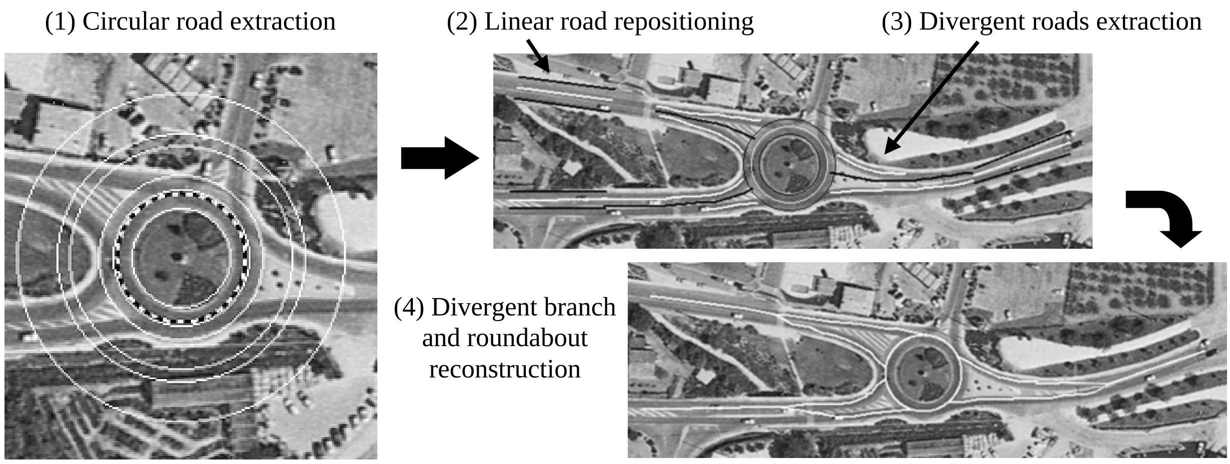

Figure 11: example of the roundabout extraction process

6 A STATISTICAL ANALYSIS OF THE SYSTEM BEHAVIOUR

Our approach is based on a decomposition of each intersection in different elementary objects, thus, to an extraction process. The main goal of a process is to certify the presence of the solution in the list of possible hypotheses. The branch and intersection reconstruction is considering all of them and has to pull up or keep the “good” solution at the top of the list. These choices are correlated to an evident over-detection for all local process. Then, the upper reconstruction level has to increase the reliability of the produced information. In the figure 12, we illustrate the system behaviour through a set of 42 roundabout’s images. These results were found by an automatic comparison between a reference (manual plotting) and the different extractions. The matching process is based on linear measure for all the elementary objects and a roundabout is accepted if all its objects are accepted. Then, if one point of one linear road is out of the tolerance, the roundabout is rejected. This method is very demanding in order to identify all the problems.

In the figure 12, we observe a reliability improvement synonym of exhaustiveness reduction. This behaviour is normal and fundamental in an automatic system with a post-correction stage. In such a situation, the operator has to visualize the invalidated intersections (in a realism sense), and correct them, or choose the adapted description in few propositions. Then, we assume that 80% of the rejected intersections (69%) should be corrected in a very short time because one linear road is wrong in a four branches intersection.

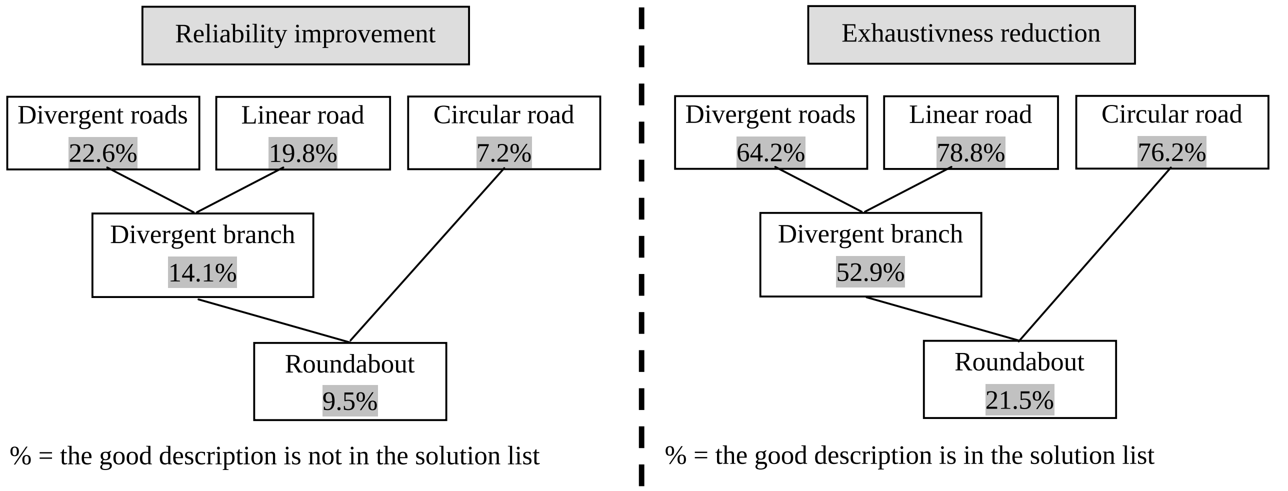

Figure 12: The system behaviour based on a statistical analysis of the roundabout example

Then, the produced information has to be classified with the realism information. So, the auto-evaluation process has to be efficient to identify the pertinent thresholds. To analyse it, we retained the best solutions of each list. We observe that 90.7% of the circular road and 92.2% of the divergent roads was corresponding to the good description. We conclude that these auto-evaluation processes are efficient. Nevertheless, the results for the linear road (78.8%) and divergent roads (71.8%) extraction illustrate the existence of problems. We consider also that these results are correlated and the improvement of the local road extraction should improve the global branch realism estimation. Finally, we analysed the evolution of information from the local analysis to the global reconstruction. The results indicate that the divergent roads process is powerful and the branch reconstruction is not damaging the information initially correct.

7 INTEGRATION IN A ROAD NETWORK EXTRACTION SYSTEM

The road network extraction is a composition of intersections and roads. To demonstrate this complementarily, we introduced some of our ideas and process in a road extraction system. The goal of this work is to propose in a short time, a prototype of a road network extraction system with a qualification of information to facilitate the post-correction.

The first idea is directly linked with the road extraction process. In the state of the art, many systems consider the road between two intersections. This hypothesis seems necessary in case of roundabout because of the circular form. But, for simple intersections, the introduction of a main road implies to prepare the external database and connect roads as much as possible. The road becomes longer and its extraction is optimized globally. This idea was introduced in the road extraction process of Guigues (2000), and the results illustrate a gain of accuracy and reliability. The second idea is the reconstruction of simple intersections, if we consider a previous extraction of the main road. The method based on the extrapolation of each secondary road in its direction seems efficient in most of situations. At least, the roundabout extraction is completely separated with the road extraction process. We consider that incoming roads are found and replace our linear local extraction. Then, the circular and divergent roads extraction is activated before the complete reconstruction process. These global and local road extractions are complementary and the conflicts inform the operator of a potential problem.

8 CONCLUSION

This paper described a knowledge-based system for the automatic extraction of road intersections in aerial images. The intersection problem and the road network extraction have to be considered separately to increase the accuracy of the road network. The simple intersection example shows that the introduction of a main road was necessary to improve the accuracy of the description. In the roundabout example, we demonstrate that our method was able to extract a complex intersection respecting the cartographic requirements. The final reconstruction filters most of ambiguous hypotheses and improves the reliability. An auto-evaluation process associates a trust measure to each intersection and its elementary objects. This measure is essential to focus the attention on the mistakes in order to correct them fast. In future, a statistical evaluation of this process will certify the significance of the decision.

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