DIGITAL STEREOPLOTTING & AUTOMATIC IMAGE INTERPRETATION : EXAMPLE OF THE ROAD NETWORK CAPTURE PROCESS

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Abstract

Within the framework of the French topographic database production, IGN[2] is working on problems related to the photogrammetric data capture automation. Based on our experience around the road network automatic extraction, this paper puts forward the highlighted difficulties as well in the field of the automatic extraction itself as in the one of the algorithms integration in an operational context. One will find a presentation and an evaluation of a semi-automatic approach, not very ambitious in terms of automation level but looking for a short term efficiency, and then an overture on the different solutions we are thinking of for a more complete automation.

Résumé

Dans le cadre de la constitution de sa base de données topographiques, l'IGN se pose les problèmes liés à l'automatisation des chaînes de saisie photogrammétrique. Basé sur l'expérience acquise autour de la restitution automatique du réseau routier, ce papier fait état des difficultés rencontrées, aussi bien dans le domaine de l'extraction automatique elle-même que dans celui de l'intégration des algorithmes dans un contexte opérationnel. On y trouvera la présentation et l'évaluation d'une approche semi-automatique, peu ambitieuse en termes de degré d'automatisation mais visant une opérationnalité à court terme, et puis une ouverture sur les différentes solutions envisagées à plus long terme pour une automatisation plus complète.

1. Introduction

IGN began around 1990 the production of a topographic database. Data acquisition consists of a photogrammetric data capture from aerial photographs at the scale of 1:30000. The database semantic content is very close to the one of traditional topographic maps (at the scale of 1:25000) with a better geometric quality (in the range of one meter r.m.s.) and 3-D coordinates for all of the objects.

The emergence of digital stereoplotters in the production lines is going to allow a part of automation in the data capture process, applying techniques coming from pattern recognition or from artificial intelligence on digital images.

One of our more advanced subjects concerns the road network stereoplotting automation, using the same photographs as those used in the manual process, digitized with a resolution around 50 cm.

The automatic interpretation, even for objects which look rather simple as roads, is a very hard task for many reasons which make that the complete automation of the data acquisition is a goal which will not be reached before many years. But it seems possible from now to make semi-automatic approaches

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operational, being less ambitious in terms of automation level but looking for a short term efficiency. The paper presents first the problems related to aerial images interpretation, then our semi-automatic approach and an evaluation of its operationality, and as a conclusion an overture on several solutions able to give a more complete automation.

2. Problems related to the photogrammetric capture automation

There are two kinds of difficulties concerning the photogrammetric capture automation : the main difficulties are related to the automatic interpretation process itself but there are also difficulties concerning the integration of automatic interpretation tools in the traditional data capture process.

2.1. Difficulties related to the automatic interpretation process

- The objects appear under various aspects in the images and one of the critical points is therefore to define a generic model of the searched objects, complex enough to detect the objects without ambiguities but taking into account the diversity within a same class. On the following figure (Figure 1), there are three examples of roads with very different characteristics in terms of shape, size and color.

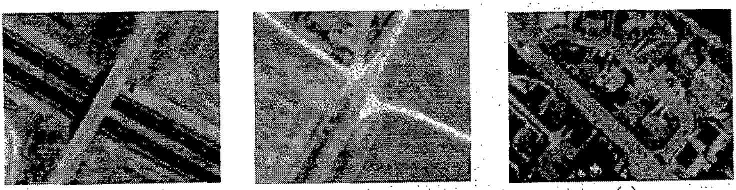

(a) (b) (c)

Figure 1 : three examples of roads

- There are often complex objects appearing in the images, complex in the sense that they are composed by several elementary objects. On the following illustration (Figure 2), there is a complex road structure composed by many little road portions, trees, shadows, vehicles, ground marks,...

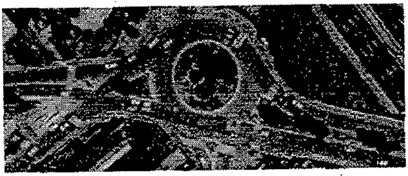
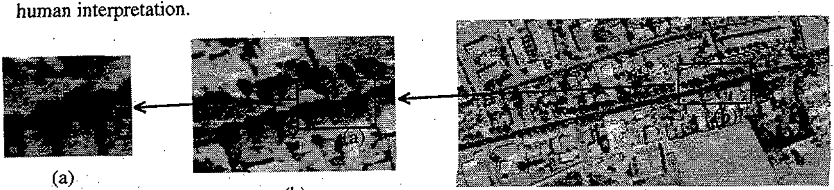


Figure 2 : example of a complex road structure

- many objects (especially roads) require a multi-scale approach to be interpreted, even in the case of a human interpretation.

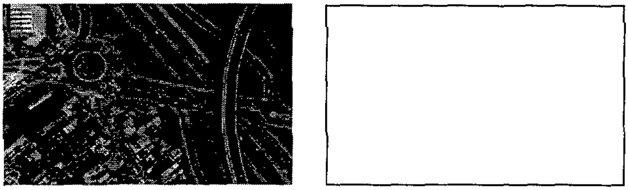


(a) (b) (c)

Figure 3 : a tree-lined road at different resolutions

On this illustration (Figure 3), there is an example where a large view is required to understand the scene. On the first image, nothing can be recognized, on the second one, we can see the trees and, only on the last one, we can see that there is a tree-lined road.

- even when the object has been successfully extracted, it is also required to put the result in accordance with the database specifications, which are not always giving a faithful representation of reality (contrary to the image). We can see on the following illustration (Figure 4) the differences between the image and the database, especially concerning the complex crossroads and the motorways.



(a) (b)

Figure 4 : roads represented in the image and in the database

2.2. Difficulties related to the integration in the traditional process

Fully automatic systems have often been described in the literature [1,2,3,4] but in front of all these difficulties, several authors begin to present semi-automatic approaches [5,6,7]. Semi-automatic methods are a good alternative to fully automatic systems in the sense that the most difficult tasks can be realized by the operator and the most time-consuming ones can be realized by the computer. The tasks which are generally left to the operator are the following ones :

- road seed indication : this stage corresponds to the object identification ("there is a road here") and eventually to an intelligent initialization of the starting conditions (choice of a specific model, knowing the context) ;
- decision making : when a problem occurs (the image does not correspond any more to the road model), the operator can decide more easily than the computer if it is better to stop or to continue ;
- control : the self-evaluation of the result by the algorithms themselves is probably the hardest task in the case of a fully automatic system. For the human operator, a fast glance is sufficient to see if the result is good or not.

The tasks which are generally left to the computer are :

- propagation of the road presence hypothesis,
- processing of a precise geometry.

But some new difficulties appear with the use of semi-automatic methods, concerning the integration of the algorithm in an interactive environment :

- real time constraint : it is easier to integrate the automatic extraction algorithm if it is able to work in real time, even if it is possible to imagine the use of a pre-computed road network with a real time display of the result.
- reliability versus exhaustiveness : it is important to give a preference to reliability versus exhaustiveness (robust stop criteria required). Manual corrections after an automatic extraction can be time-consuming and it is better if the algorithm gives no answer rather to give a bad answer.

- user contribution versus reliability : the more important the user contribution is, the more reliable a semi-automatic method has to be. For example, with methods only based on active contours techniques, the user has to manually indicate an approximate plotting as an initialization of the automatic extraction and it is essential with this kind of interaction to have an important success rate. With other kinds of interaction, with a less important user contribution (only one manually indicated point), it is possible to accept a larger error rate.

3. Semi-automatic approach : the road following algorithm

3.1. General presentation of the method

The main originality of the method is to divide the road extraction process in two successive stages [8] : one for the rough detection of the road (using only radiometric constraints) and one for the computation of a precise geometry of the road axis (using only geometric constraints). This division is based on the following observations :

- the absence of geometric constraints allows to ensure the detection continuity even if the road is partially screened by obstacles (shadows, trees, vehicles,...),
- a too strict geometric constraint in the detection step would not permit to fit the roads layout diversity. As much as a highway line corresponds to a constant geometric representation, as variable the plotting of secondary roads is,
- geometric constraints can not be correctly applied on too local portions of roads.

3.2. Detection step

The road following algorithm is mainly based on the optimization of a textural criterion. Knowing that roads are elongated homogeneous areas, we optimize a directional homogeneity criterion [8] computed on a long enough distance to be characteristic of the specific texture of roads, which is not isotropic (roads are elongated objects and their homogeneity may be measured along the road axis). Optimizing the criterion on a large set of segments allows to fit the road shape and to cross over obstacles.

Local computation of the homogeneity : the gray-level variance is computed in the possible propagation directions on elongated neighborhoods with variable length (Figure 5). The next possible locations are computed according to the length and the direction of the neighborhood which minimizes the variance.

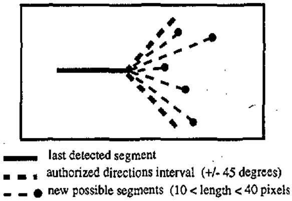


Figure 5 : local computation of the homogeneity

Choosing the best path : using this measurement of the local homogeneity, we compute at every new location on the road a tree of possible paths (a path is a set of segments) by retaining at every level of depth the most homogeneous segments around the current propagation direction. Once the tree has been built (Figure 6), the best path is determined as the one which minimizes the variance, maximizes the total length, and which is the most rectilinear (this last component of the cost function must not be considered as a geometric constraint, it rather gives a little preference to the most regular path when there are many paths with the same homogeneity). Keeping the best path in the tree allows to make the road-following more reliable, and to cross high curvature areas (Figure 6), or obstacles (change of road surface, trees, vehicles, ...).

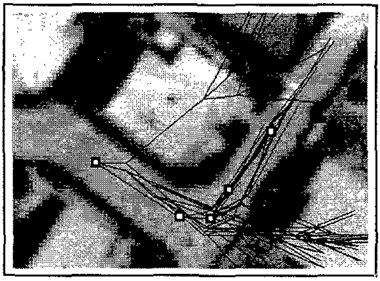


Figure 6 : tree of the possible paths
(white squares for the best path)

3.3. Geometric adjustment step

The so detected roads do not have a precise geometry since the homogeneity criterion just ensures to find a way between both road edges. We have now two ambitions : to smooth the result to give a "cartographic aspect" to the plotting and at the same time to keep a good adjustment on the points which have been recognized with the right geometry. We need for that task a method which tries to estimate locally the road center position and a method to smooth the plotting between these positions.

Road edges detection : during the detection step, a road edges detection is performed, on one hand to adjust the axis of the road (if possible according to the quality of the detection), on the other hand to compute confidence indicators on the extracted network geometry, in view of an *a posteriori* adjustment. The used technique consists in assimilating locally the road edges with line segments, and looking for the best pair of parallel lines in a gradient image computed through the direction perpendicular to the current road orientation.

Geometric adjustment using Splines : we use second order Splines to smooth the detected plotting especially at the locations where no parallel edges have been extracted.
It gives a good representation of our plotting because :

- Roads are rather well represented by curves with a minimal curvature. We use here quite the same geometric model as the one used in the active contours methods, frequently employed for road restitution problems [8].
- Weights can be introduced in the Spline computation to take into account with a more or less importance the different points according to the confidence we have in their location.

3.4. Stop criteria

The road-following process can stop on several criteria : too high variance, rough change of the mean radiometry, or wide dispersion of the seeking tree. The latter is the most discriminating, taking into account the anisotropic aspect of the roads homogeneity (avoiding, for example, that the plotting get lost in a field whose radiometry (grey level and texture) would be close to the one of the road).

4. Semi-automatic approach : the user interface

To evaluate the possible contribution of our method in an operational context, it is necessary to implement it on a prototype to be tested by operators which are used to the manual data capture. This prototype has to integrate different kinds of functionalities, some of them are common to all systems using digital images or to all Geographic Information Systems, others are specific to the semi-automatic road extraction.

4.1. Common functionalities with systems using digital images

- images management : we have to work on large dimension images (at least one high resolution stereo pair = 2 x 6000 x 12000 pixels). As the real-time constraint requires a fast access to data, we are working with compressed images to reduce the reading time on disk. The compressed images are decompressed on-line when the working area changes.
- display management : different views with different resolutions are necessary to allow the capture, the control, the choice of a new working area,...

4.2. Common functionalities with GIS

- data structure management : we need a simple graph structure to modelize roads (as edges) and crossroads (as nodes).
- manual data capture tools : we need a simple data capture tool to digitize manually, point by point, roads which can not be automatically followed.
- graph manipulation tools : we need all the standard GIS tools, such as object destruction (complete or partial), displacement, connection to an existing object, ...

4.3. Specific functionalities

- automatic extraction tool : the automatic extraction module can be activated from two manually indicated points (one point, one direction). Then, the automatic propagation can stop by itself or be stopped by the user. The automatic tool has to work in real-time, quickly enough to be more efficient than the manual capture but not too fast to authorize the operator on-line control.
- fast transition between the manual mode and the automatic mode : when a road is being automatically extracted, the user may have to digitize manually a few points if there is an obstacle and to return easily to the automatic mode.
- automatic connection to the other objects : in the case of automatic plotting, the algorithm has to be able to find automatically the connections with existing objects and to choose if the best connection is the prolongation of the last segment or the connection to the nearest point.
- last point elimination : when the road following algorithm stops, it is sometimes to late... It is necessary to have a function which gives the possibility to go back quickly to the last right point.
- semi-automatic data correction tool : the geometric adjustment gives sometimes bad results (when the road edges are not sufficiently contrasted) but its failures are always the same ones. They can be corrected using a specific tool which displaces not only one point but all its neighborhood.
- use of multiple resolutions : with the automatic extraction, the resolutions used for the computation and for the display are totally independent. We hope that it will be faster to compute the result using a high-resolution image and to display it on a lower resolution image.
- computation of the z values : the 2-D visualization requires (even for the manual capture) a post-computation of the z values, using an associated DTM or locally trying to match road profiles from both images of a stereo pair. This functionality has not been implemented.
- journal file management : it can be interesting to store all the user's actions to analyze his behavior and compute statistical indicators.

5. Semi-automatic approach : evaluation of the method operationality

5.1. Methodology

What kind of evaluation ?

Evaluating the operationality of an automatic (or semi-automatic) extraction method is a complex problem, so numerous the parameters are, which can have an influence on the final result :

- influence of the image : the term "image" recovers here several meanings, referencing either the landscape influence (urban area, sub-urban area, rural area, regional specificities), or the quality of the digital image (noise, contrast,...), or the resolution of the image,... This is probably the most important parameter and it seems difficult to understand its influence without making a lot of experiments.
- influence of the operator : it can be interesting to evaluate the influence of the user experience (Does it exist an optimal use of the algorithm ? Does the operator use better the algorithm with training and practice ?) and of the user's knowledge (Does the operator use better the algorithm if he knows how it works ?).
- influence of the road following parameters : this evaluation especially concerns the thresholds attached to the stop criteria. The thresholds values will fix the ratio between reliability and exhaustiveness (With low thresholds, the algorithm will often stop but will never fail. With high thresholds, it will fail more often and manual corrections will be required.)
- influence of the user interface : the user interface plays an important role in the efficiency of all the interactive applications. One of the important parameters is maybe here the resolution of the displayed image.
- influence of the hardware : with a more extended memory (to have the whole image in memory) and a faster processor, the automatic extraction would be more efficient.

The most interesting measurements we can make to evaluate the final result according to these parameters are the geometric quality of the results (which has to fit the geometric specifications of our database) and the data capture times (which have to be as short as possible and at least shorter than the manual data time).

The reference data to use for the evaluation are easy to design : the semi-automatic extraction has to be compared with the manual data capture. Concerning the geometric quality, the standard deviation of the differences between both graphs (manual & semi-automatic) may be less or equal than the one given by the database specifications (2,5 meters on crossroads, 1 meter on roads). Concerning the data capture time, the automatic extraction has to be faster than the manual one.

The evaluation we propose in this paper will be incomplete : the realized measurements concern only 4 images (Figure 7 : 3 different areas with two resolutions on the same area) without analyzing the other parameters :

name	*photo scale*	*digitizing step*	*ground resolution*	*landscape*	*network length*
Montpellier	1:30000	20 µm	60 cm	urban	55 km
Valréas1	1:30000	20 µm	60 cm	sub-urban	20 km
Valréas	1:20000	20 µm	40 cm	sub-urban	20 km
St-Cast	1:30000	15 µm	45 cm	rural	22 km

Figure 7 : description of the test areas

Geometric quality : The method we use consists in matching both graphs we have to compare and then in computing statistical indicators such as means, root mean squares and standard deviations.

To match both graphs, the methodology consists in :

- cutting the first graph into equal length segments.
- looking for the nearest neighbor of each point of the first graph on the second one by measuring a "point to segment" distance. This measurement is not symmetrical and we will have to match each time the first graph with the second one and the second one with the first one.

As we can see on the figure (Figure 8), the difference between both measurements can show a generalization level difference between both graphs. If the graph (2) is more detailed than the graph (1), the distance 2-->1 will be greater than the distance 1--> 2.

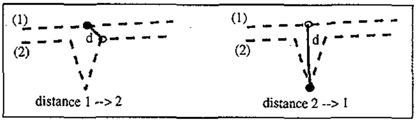


Figure 8 : both possible matching between graph (1) and graph (2)

To compute the statistical indicators, we compute from the distances histogram a threshold to eliminate the aberrant ones. For this reason, we associate to each measurements serie a threshold and the proportion of rejected points.

Extraction times : to compute the extraction times, we use the journal file which has been created during the session with the dates corresponding to each action.
The different times which are interesting are :

- the total time of the session,
- the automatic extraction time,
- the manual data capture time,
- the "interruption time" which represents the elapsed time during all the stops of the road following,
- the "moving time" which is the access time to the image when the working area changes,
- the "correction time" which is the time taken by all the operations on the graph.

The total time will never correspond to the sum of the other measured times because :

- there is always an important time of "inactivity",
- moving time is also included in the extraction times.

For the data capture times (total, automatic and manual), we can associate the road network length to the time measurement to give an idea of the data capture speed.

5.2. Geometric quality evaluation

We only performed the geometric evaluation on two test areas : Valreas2 and St-Cast. On the first area (Valreas2, Figure 9), the semi-automatic extraction (called auto) is compared to a manual extraction (called ref) and to the existing database (called BDT for Topographic DataBase). On the second area (St-Cast, Figure 10), we have two semi-automatic extractions (called (1) and (2)) to compare to a manual extraction (call man).
All results are given in meters (from the mean resolution of the images).

VALREAS2 Roads	n	threshold	% rejected	mx	my	mxy	σ xy	rms xy
auto - ref	1748	3,4	2,6	-0,05	0,12	0,67	0,92	0,93
ref - auto	1680	3,9	38,3	0,05	-0,15	0,71	0,97	0,99
auto - BDT	1751	5,4	2,4	0,04	0,15	1,20	1,53	1,54
BDT - auto	1681	6,3	36,4	-0,01	-0,17	1,29	1,69	1,70
BDT - ref	2621	5,1	3,8	0,03	-0,05	1,08	1,42	1,42
ref - BDT	2617	4,9	0,9	-0,03	0,03	1,05	1,37	1,37

Figure 9 : geometric evaluation of the roads for the Valreas2 area

ST-CAST Roads	n	threshold	% rejected	mx	my	mxy	σ xy	rms xy
(1) - man	2123	2,9	3,8	0,20	0,20	0,60	0,75	0,80
man - (1)	2059	2,9	5,3	-0,19	-0,21	0,61	0,76	0,82
(2) - man	1581	2,7	0,7	0,13	0,08	0,58	0,76	0,77
man - (2)	1529	2,8	29,7	-0,13	-0,09	0,59	0,76	0,78
(1) - (2)	1552	2,7	29,6	0,04	0,08	0,43	0,68	0,69
(2) - (1)	1550	2,4	2,6	-0,05	-0,08	0,43	0,67	0,67

Figure 10 : geometric evaluation of the roads for the St-Cast area

As explained in the 4.2.1. paragraph, we performed double measurements to see if both compared networks have the same level of details (in this case, both measurements would be equal).
We can see on this different tables that :

- the geometric accuracy specifications are globally respected (less than 1 meter).
- measurements are perfectly symmetrical (no difference between the mean distance (1) to (2) and the mean distance (2) to (1)) and we may conclude that the automatic extractions have the same level of details than a manual extraction.
- the automatic extractions geometric quality seems to be a little better than the existing database (see Figure 9, best results between auto and ref) and than a manual extraction (see Figure 10, best results between (1) and (2)).

5.3. Extraction times evaluation

For each of our four test areas, we have done (Figure 11) a comparison between the manual extraction and the semi-automatic one, in terms of performances : extraction times and length of the extracted networks.

	total time (mm:ss)	total length (km)	total speed (km/h)	auto time (mm:ss)	auto length (km)	auto speed (km/h)	manual time (mm:ss)	manual length (km)	manual speed (km/h)
Montpellier (manual)	49:03	49,0	59	▨	▨	▨	31:56	49,0	92
(semi-automatic)	47:44	54,5	68	12:32	37,8	180	5:52	16,8	171
Valreas1 (manual)	18:22	17,2	56	▨	▨	▨	12:38	17,2	81
(semi-automatic)	17:11	19,3	67	4:41	14,7	188	1:28	4,6	187
Valreas2 (manual)	12:27	16,1	77	▨	▨	▨	9:31	16,1	101
(semi-automatic)	9:29	14,7	93	2:43	12,6	277	1:24	2,2	93
St-Cast (manual)	26:46	19,7	44	▨	▨	▨	19:15	19,7	61
(semi-automatic)	16:22	22,2	81	5:11	19,1	221	1:20	3,0	136

Figure 11 : extraction times and speeds for semi-automatic and manual extractions

We can see on this table that :

- semi-automatic extraction always allows to save time but never allows to save much time... In a rural context, the ratio between the semi-automatic extraction time and the manual extraction time is 1 to 2, in an urban context, the ratio is 1 to 1,2.
- a great part of the network can be automatically extracted (70% in an urban context, 85% in a rural context).
- even when a great part of the network is automatically and quickly extracted, we do not save much time because of the "inactivity" time related to all interactive processes.

5.4. Conclusion

It is too early to conclude definitively about the operationality of our semi-automatic road network capture method and many other tests will be necessary to confirm our first conclusions. These conclusions are :

- it is possible to save time with a semi-automatic method, even with the present version of the algorithm which is only able to follow simple roads (without obstacles or complex configurations).
- the semi-automatic method seems to be more efficient in a rural context, with long road portions (few crossroads) and sinuous plotting (which require a time-consuming restitution in the case of a manual capture).
- it seems to be difficult to save much time with a semi-automatic approach because of all the time lost by the displacements into the image and by the the period of latency between the end of one action and the beginning of the next one.
- the geometric accuracy of the result is correct compared to our specifications (less than 2 pixels r.m.s.)

6. Perspectives : going to a more complete automation

If the semi-automatic method is already able to save time, a more time-saving solution will come with a complete automation of the process. For this complete automation we have to work in both following directions :

- more reliability : the algorithm we have, even if it can only follow one kind of roads, is able to detect 70% to 85% of the network. If we succed in validating automatically such a proportion of the data capture, the saved time will be important.

- more exhaustiveness : the other way to increase the productivity is to try to automate the capture of all kinds of roads in all kinds of contexts, even when the road continuity is interrupted by an accidental occlusion. This part is not completely separated from the first one in the way that a good validation of the simple roads will require a complex interpretation using the objects of the context (houses near the road edges, vehicles on the road,...).

On top of the semi-automatic method, we are trying to work at the same time on other approaches to automate more completely the road network capture :

- an approach using external data to guide the automatic detection : The use of external data (such as digitized maps [9] or small scale database [10]) allows to initialize the detection with an approached localization of roads and to take into account a rich semantic knowledge to guide the automatic extraction. The semantic knowledge corresponds on one hand to the road attributes (importance, number of lanes,...) and on the other hand to the spatial relationships between roads and all the objects of their neighborhood (landcover, buildings, hydrographic network,...). This knowledge can be used to choose between different algorithms or between different parameters, in order to fit the algorithm's behavior to the different contexts and to increase the detection exhaustiveness.

- a fully automatic approach using only the image and a generic knowledge of the searched objects : this approach [4] is based on an automatic detection of the road seeds and uses then our road following algorithm as a reliable initialization of the interpretation process : each stop of the algorithm is interpreted as an obstacle presence hypothesis (tree line, shadow, ...). The obstacle is then identified using several "specialists", each of them being able to recognize one kind of obstacles. This recognition allows to confirm the road presence hypothesis and to ensure the plotting continuity through the obstacle.

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