AUTOMATIZED UPDATING OF ROAD DATABASES FROM SCANNED AERIAL PHOTOGRAPHS

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ABSTRACT

The aim of this paper is to present our approach and discuss preliminary results on automatizing the updating of a road database using scanned aerial photographs.
Image understanding, easily performed by human operators, is the bottle-neck in automatizing photogrammetry. The complexity of aerial photographs requires the use of context information for object recognition. We show that the concept of a multi-stage approach can create a context that influences or guides the computer interpretation. The multi-stage approach embeds a two level approach for image analysis. The low level contains several image processing techniques for segmentation. The high level guides the segmentation by inference. It integrates knowledge sources, e.g. a priori information present in an existing database.
We discuss in detail the verification whether a road segment in the database is present in the aerial image at the hypothesized location. It illustrates the huge complexity of aerial image interpretation.

Keywords: Image analysis, Data Base, Change Detection, Map Revision.

1. INTRODUCTION

The ultimate aim of our present research activities is to design a system that is able to update a road database at a high degree of automation. (Semi)-automatic updating of topographic databases is highly desirable since the need for high quality geo-information at all levels of geo-management is evident. However not the production of aerial photographs and satellite images forms the bottle-neck in the geo-information supply, but the photogrammetric processing of the image data. In its present form it is time consuming and labour intensive.
Characteristic for digital photogrammetry as opposed to analytical photogrammetry is access of the computer to the contents of the image, because it is stored in a digital form. This creates the possibility to use digital image processing tools for the development of fully automatized photogrammetric systems.
Geometric tasks, such as aerotriangulation and orientation, can at present nearly be solved automatically by transferring experience from analytical to digital photogrammetry. However tasks involving interpretation capabilities of human operators are very difficult to solve by computers. Image understanding is the research field of computer vision and artificial intelligence. The updating problem can be approached as an image understanding problem. A strategy is to formalize domain-specific knowledge of a human operator and implement it in digital photogrammetric systems. For image analysis and change detection we also use a priori knowledge present in an existing database, or more generally, GIS knowledge. (Lemmens, 1988; Lemmens, 1990)

Our research domain is the updating of road databases. Roads express the principal structure of areas and their extraction from aerial photographs and satellite images is the subject of more research (e.g. McKeown and Denlinger, 1988; Cleijnenbreugel et al., 1990; Fischler et al., 1981; Gunst et al., 1991, to mention a few). In contrast with this previous work we use a priori knowledge from a topographic road database.

At present we emphasize the concepts for the design of the system, especially the integration of knowledge sources and digital image processing techniques at the conceptual level. So implementation aspects, such as data structures, storage and manipulation of knowledge, communication of the control mechanism with the data and the image processing routines are not considered.

This paper is structured as follows. The next section discusses the complexity of interpretation of aerial images. This leads to the definition of concepts for this interpretation in section 3. Section 4 illustrates the presented concepts by a casestudy.

2. COMPLEXITY OF INTERPRETATION OF AERIAL IMAGES

Image understanding, easily performed by human operators, is the bottle-neck in automatizing photogrammetry. The traditional approach for automated interpretation is to describe each object with a number of descriptive attributes. Their values are compared with values of a prototype, stored in a model base. This approach is realistic when only a small number of parameters is necessary to describe each object in an unique way. It is always possible to develop a procedure that nearly perfectly interprets a test-image with respect to a certain task-domain. However such a method is often developed by an exhaustive trial-and-error process and therefore it relies heavily on characteristics of the test-image, like types and manifestation of objects. If these characteristics are stable, the procedure may operate successfully on future similar images. Interpretation of images that even just slightly deviate from the prototype tends to fail. The assumed stability of conditions is realistic in industrial environments. Typical in an industrial environment is the limited number of objects in object space and their isolated location.
Interpretation of aerial images is a very hard task, due to the following characteristics of the image:

- Objects in images of natural scenes need to be embedded in more extensive contexts, rather than treating them as independent objects. Many objects, like bridges and fly-overs, receive their meaning in the context in which they appear. So we need recognized objects to create a context for the interpretation of other objects.

- The same type of objects can appear in a wide range of representations in an aerial photograph. So it is very difficult to build a prototype that describes each type of objects unambiguous. Moreover the definition of an object is task-domain dependent. Additionally the appearance of one and the same object is not stable, due to changes in recording circumstances, like sun angle and season.

So, in images of natural scenes the assumption about stability is violated, resulting in poor results for images that even just slightly differ from the test image. Consequently the traditional trial-and-error procedures are unsuited for solving the interpretation problem of aerial images completely.

3. CONCEPTS FOR INTERPRETATION OF AERIAL IMAGES

The need of context to interpret images of complex object spaces, brings us to the conclusion that a multi-stage recognition procedure is required. That means, in simple terms, that a small part of the image may already have been recognized, while other parts of the image are still in the raw image data stage. The recognized parts influence or may even guide the further recognition process.

Because of the variability in appearance of objects, we need an integration of different segmentation techniques, guided by a control level. Hence we adopt the usual two level approach (Nazif and Levine, 1984; Tenenbaum, 1973). The task of the low level is segmentation and the high level's task is interpretation of these results.
Interpretation at the high level may be looked at as a process of hypotheses generation, testing and updating.

For all possible changes that a road may undergo, hypotheses should be generated.
Testing these hypotheses means following a path in a tree with many branches, where at each branchpoint one has to take a decision which branch to follow. It is our believe that the path should depend on the characteristics of the data, the type of object and the task domain. In this way knowledge from different sources is integrated.
During the interpretation process new knowledge becomes available, derived from the image data. Consequently hypotheses have to be updated during the interpretation process. Therefore the condition part of the decision rule, examined at each branchpoint, should not be fixed, so it can be adapted. Parameters, like the values of thresholds, need to be determined during the interpretation process. Our idea is to use the a priori information present in the database, to determine among others initial values of these parameters.
The order of hypotheses testing is also of importance, introducing the problem of the creation of a hypotheses hierarchy.

The next sections will describe how the multi stage and two level approach can be used for automatized road updating.

3.1 Multi-stage approach

The concept that different parts of the image are in different stages of processing, requires a strategy to guide the major steps of the hypotheses hierarchy. It is task-specific and depends on input and required output. Our input is a road database of the old situation and a scanned aerial photograph of the present situation.

The basic real-world knowledge of our strategy is that roads form a connected network. A network can be considered as a graph, consisting of nodes and arcs between nodes. Nodes are for example crossings and fly-overs. Arcs are road segments that start and end in a different node or at the side of the image.
Using the multi-stage approach, arcs and nodes will be extracted in different stages of the process. Arcs have features that are easier to extract than features of nodes. Features of nodes are also more dependent of the type of node. Hence arcs are examined first in each step of the strategy, which in fact is an interpretation of road segments. They create a context for interpretation of nodes, so a hypothesis for the location and type of the node can then be made. This simplifies segmentation and interpretation of the nodes.

The first part in the strategy aims to determine three characteristics of the road network: (1) the approximate location of road segments and nodes, (2) which road segments are connected by each node, and (3) classification of parts of the road network for example as crossing, fly-over or bridge.
It has to be investigated first if roads indicated in the database are still present in the aerial photograph. We use the location of the road in the database to indicate the location in the image, assuming that the geometric interface between database and image has been established correctly in a preprocessing stage. Properties of roads that are confirmed can be used to extract new roads, connected to the confirmed roads, which create the context. Finally in the complete image new roads are searched, that are not connected to the road-network or which are connected, but not found by the previous steps.

The next step is a local analysis of the regions where roads were detected, to determine the accurate position of the road.

3.2 Two level approach

The problem is to bridge the gap between the image, which is a two-dimensional intensity array, and the object models. We use a two level approach. The high level should assign the appropriate interpretation to objects within the scene. Therefore the image must first be segmented into regions, that roughly correspond to objects, contours or parts of objects. This is the task of the low level. This level contains several segmentation techniques.

LOW LEVEL
At this low level we distinguish commonly two types of segmentation techniques are distinguished:

1. Those which produce edge information, based on discontinuities between regions. In the real world these continuities correspond to the road boundary. Some examples of techniques are edge enhancement thresholding and optimal path searching.

2. Those which produce surface information, based on homogeneity and spectral properties of regions. In the real world they correspond to road surface. Region growing is an example of such a technique.

To decide about the presence of a road, results of both types of segmentation techniques should be combined.

HIGH LEVEL
The primary goal of the high level is (1) to select the most efficient segmentation technique, (2) to evaluate the performance of segmentation techniques, and (3) to test hypotheses about interpretations, which leads to the next step of the hypotheses hierarchy.

The high level integrates knowledge from several sources:
- real-world knowledge;
- knowledge about the old situation in the road database;
- knowledge about operating characteristics of segmentation techniques;

We discuss these knowledge sources in the next sections.

3.2.1 Real-world knowledge

Automation requires formalization of the (unconscious) knowledge that a human operator uses, when extracting an object from an image. This so-called real-world knowledge is task-domain dependent.

To bridge the gap between the real-world knowledge and the segmentation results, we need a description of the real-world knowledge with the same features as extracted from the image. Hence we define the appearance of objects and their contextual relations with descriptive attributes such as grey value, size, shape and texture.

3.2.2 Knowledge from the road database

The existing road database provides a large amount of information, among which: location, width, and type of nodes. It can give a hypothesis for the location of roads. If it has been verified that roads in the database are still present in the digital image, descriptive attributes of roads can be extracted and used for the segmentation of parts of the image with the same properties as the verified roads.

3.2.3 Knowledge about operating characteristics of segmentation techniques

Testing a hypothesis about the presence of a (part of the) road network requires that the result of the segmentation is evaluated and eventually cleaned-up. It is often possible to obtain a better result by using other parameters, for example another value for a threshold or another width of the region of interest. The result of a segmentation technique might be easier to use for testing of hypotheses, if it is first cleaned-up, for example by joining two collinear unconnected line-pieces.
For this purpose knowledge about the operating characteristics of segmentation techniques is needed.
The problem is that not much research has been done on expressing this knowledge in measures for the quality of the segmentation result. In addition a procedure for the cleaning-up should be defined for each segmentation technique.

4. CASESTUDY

In this section we illustrate the presented concepts by an example. In particular we describe how explicit knowledge may guide the segmentation.
We wish to verify if the roads in the road database are still present in the scanned aerial photograph. This is only a minor part of the procedure for automatized updating, but it illustrates very well the complexity of the problem. The strategy followed arises from the nature of the object (a network), and the nature of the task (updating). This task results in an extra knowledge source: a road database.

Real-world knowledge
- Roads are connected to form a network;
- A network consists of nodes and arcs;
- Roads are linear structures with restricted and relatively constant width;
- The edges of the road are usually parallel

Knowledge from database
- The location of roads in the old situation is known in the image space
- Properties of road types and road features can be determined in object space (e.g. width and distance to adjacent parallel road)

In fig. 1 the present state of the road database is shown, representing the "old" situation in object space. Fig. 2 shows an aerial image of the present situation in object space. The image is the blue part of a true colour aerial photograph, scanned in blue, green and red with pixel size 1.60 m.. The present situation shows a crossing instead of the T-junction in the old situation. It connects a new road to the network, which crosses the highway by a fly-over. In addition a new exit and a new slip-road are present.

The high degree of complexity will be illustrated by considering just a single road segment, taken from the database. Its axis represents an arc of the road network in the database. The road segment is superimposed on the image (see fig. 2).
Since the location and orientation of the road is approximately known, only a small region of interest (ROI) around the road segment can be examined. Using the real-world knowledge that roads are linear and have parallel boundaries, a region of interest is defined, such that the ROI rows are perpendicular to the local direction of the axis of the road. The road boundaries in the region of interest form straight lines parallel to the ROI columns. In this way the ROI can handle any type of curvature. The width of the ROI depends on the known road width and the distance to adjacent parallel roads, stored in the database.
Fig. 3 shows the region of interest of the road segment in fig. 2.

4.1 High level: hypotheses generation

All possible changes that a road segment may undergo, should be defined to verify if the road segment is still present. With respect to the presence of the road segment, at least the following hypotheses should be tested:

- The road segment is still present;
- The road segment does not exist.

If the road segment is still present, we should test whether:

- Its properties have remained entirely unchanged;
- The width of the road segment has changed;
- The curvature of the road has changed;
- The road is crossed by a new road. The new node is a level crossing;
- The road is crossed by a new road. The new node is a fly-over, where the new road is at the high level;
- The road crosses a new road. The new node is a fly-over, where the new road is at the low level.

These hypotheses are not mutually exclusive. For example the width of the road may have changed, while the road is simultaneously covered by a fly-over. Hypotheses can even be highly correlated. For example, if the curvature of the road has changed, it is also likely that the width of the road has changed.

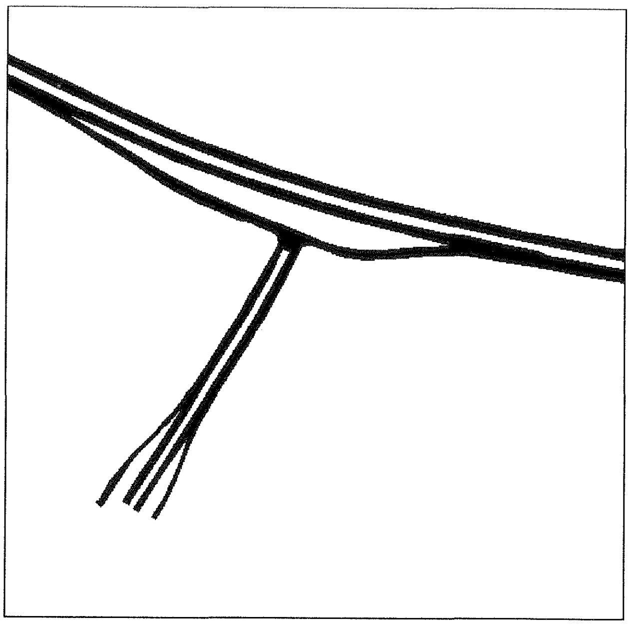

***Fig. 1** Part of the road database expressing the old situation.*

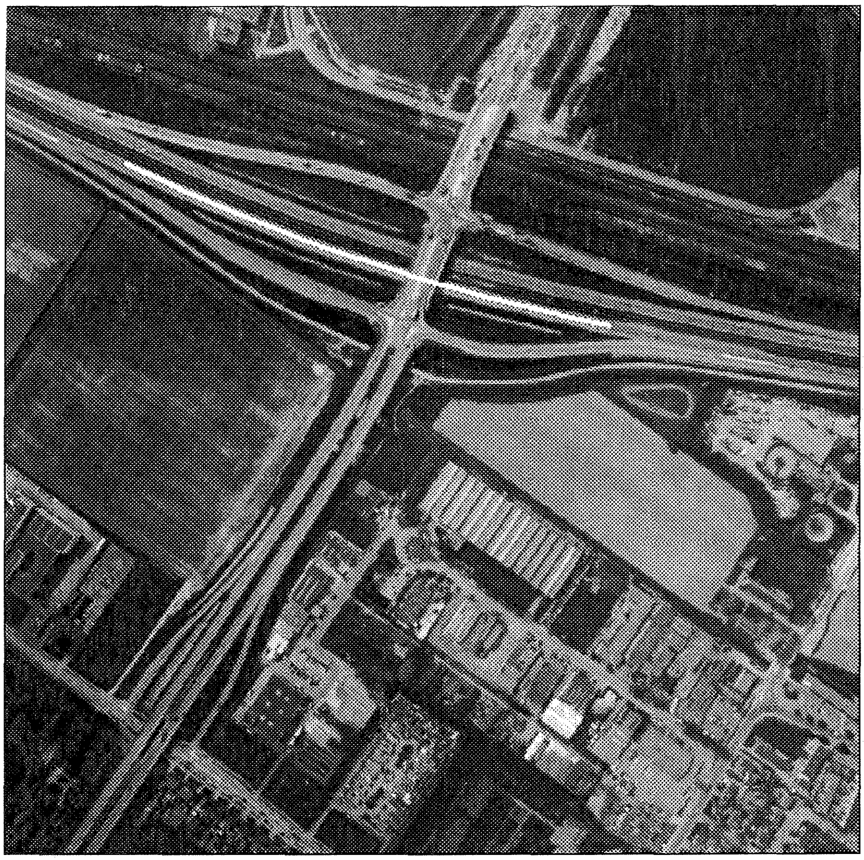

Fig. 2 *Blue band of a scanned colour aerial photograph, pixelsize 1.60 m., representing the present situation. The considered road segment from the database is superimposed on the image in white.*

This introduces the difficult task of hypotheses hierarchy. That means: What should be the sequence of the hypotheses to be tested.
To test the last hypotheses, we need the result of the first two. Real-world knowledge can be used to determine the hypotheses hierarchy.

Real-world knowledge
- Roads are in general hard topographic objects, that have a low probability to be removed.

Using this knowledge the first hypothesis to be tested should be whether the road segment is still present.
Then the problem is faced of choosing appropriate segmentation techniques to test the hypothesis. This choice should at least depend on the following criteria:

- The segmentation techniques should produce relevant parameters, for example the width of the road, that can be employed during hypothesis in a subsequent stage of the road hypotheses hierarchy;
- They should agree with characteristics of the data, for example the noise level and pixel size (satellite images require other techniques than large scale aerial images);
- They should agree with the type of object, for example for testing the presence of an hypothesized fly-over, we could use a technique that detects shadows.

To be able to make this choice, we need knowledge about operating characteristics of segmentation techniques, knowledge about the image data and real-world knowledge.

Fig.3 *Region of interest (ROI) defined by the road segment. The ROI was extracted from the image by resampling*

4.2 Low level: segmentation techniques

We will discuss two segmentation techniques, which both detect road boundaries. Both do not result in a final decision at the high level, since they do not provide enough information to base a decision on. In addition other segmentation techniques that provide information about road surfaces have to be applied.

The boundary of the road is characterized by:

> ***Real-world knowledge***
> - The grey value of the road contrasts with the grey value of adjacent terrain;
> - The curvature of the road is bounded;
> - The edges at both sides of the road are usually parallel.

Many segmentation techniques can handle boundaries with the above characteristics. We choose:

Edge enhancement/Thresholding
Based on the assumption that the grey value of the road contrasts with the adjacent terrain, we use an edge detector for extraction of the boundary of the road. The edge responses are thresholded and skeletonized to one-pixel thick lines.

Dynamic programming in a restricted ROI (Gerbrands, 1988)
Dynamic programming is a general optimization technique that searches for a path with a maximum cost solution. Appropriate costs should indicate the significance for the presence of an edge of the road. The edge strength of all pixels in the ROI leads to appropriate costs. Now the problem can be formulated as tracing a maximum cost path.

Results of both techniques are shown in fig. 4 and 5. In fig. 4 can visually be observed that three broken boundaries have been traced. In fig. 5 can be seen that the path is bendy at the position where the fly-over is present in the new situation.

4.3 High level: analysis of segmentation results

In order to reach the above conclusions by reasoning at the high level, we have to include knowledge about operating characteristics of both segmentation techniques.

> ***Knowledge about operating characteristics***
>
> *Edge enhancement/thresholding*
> - A boundary in the real world may be broken into unconnected line-pieces in the segmentation result;
> - Separated boundaries in the real world might be connected in the segmentation result;
> - If an edge runs over the complete length of the region of interest there is high evidence that it represents the boundary of the road;
> - Edges in the row direction of the region of interest that break long edges in two parts, may indicate the presence of a new fly-over.
>
> *ROI restricted dynamic programming*
> - Dynamic programming will always trace an optimal path, since the a priori assumption is that a boundary is present in the ROI.
> - If more roads are present in the region of interest the maximum cost path can jump from one road to another road;
> - The maximum cost path is bendy if the road is interrupted by a node or a small bright object close to the road;
> - The detected path for the left and right side of the road should be approximately parallel.

We use this knowledge for two purposes:
1. evaluation and clean-up of the segmentation result;
2. testing of hypotheses.

They will be successively described.

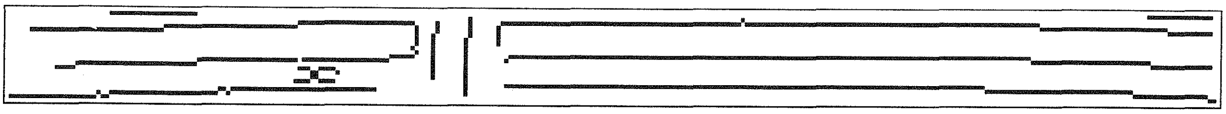

Fig. 4 Result of edge enhancement/thresholding scheme and subsequent skeletonisation applied on the ROI of fig.3

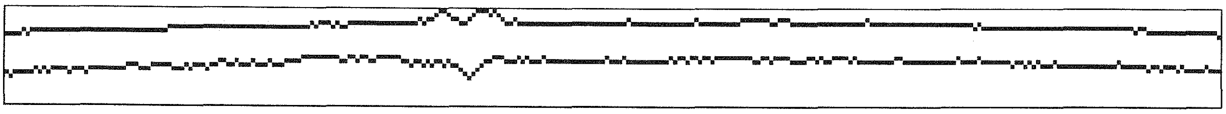

Fig. 5 Result of dynamic programming applied on the ROI of fig. 3

Evaluation and clean-up
Procedures are required that detect the above operating characteristics.
In order to detect unconnected line-pieces, the skeleton is vectorized. For each segment the direction is computed. The decision whether the line segments will be connected is done by a length-weighted direction table. The problem is to decide whether fragmentation of the road boundary is due to the segmentation technique or due to a new node.
Another procedure has to be defined that detects parallel boundaries in the region of interest. One method is to detect jumps in the maximum cost path. Their detection results in adaptation of the width of the region of interest and an assumption for the location of another (parallel) road.

Testing of hypotheses
In fig. 4 three boundaries run over the complete length of the region of interest, but there is a gap. The presence of the road is first checked for the parts at both sides of the gap. Fig. 6 shows how the region of interest was splitted in two candidate arcs and one candidate node. The boundaries in the candidate arcs run over the complete length of the region of interest, so there is evidence for the presence of a road segment. However, also canals have parallel borders. So the conclusion is not unique and further evidence has to be found by combining edge information with surface information.
When checking edges in the candidate node, edges will be found perpendicular to the boundaries in the candidate arcs. This indicates high evidence for the presence of a fly-over, but this hypothesis is tested in another stage of the process.

4.4 High level: control

After analysis of the segmentation result, the next step in the hypotheses hierarchy has to be determined. Control by the high level consists of two parts:
1. local and context confirmation of the candidate road segment;
2. updating of the evidence of the interpretated objects.

Local and context confirmation
If evidence has been found for the presence of a road boundary, it needs to be confirmed by evidence of a road surface. The hypothesis that the road is still present is accepted on bases of local evidence. It is known that roads form a connected network. Hence we can use context information to find evidence for this hypothesis. Suppose the evidence of the candidate node increases in a next step, than the evidence for the two adjacent candidate road segment increases.

The problem of the high level is: When is enough evidence gathered to accept a definitive hypothesis? For example: How many segmentation techniques should be used before enough evidence is gathered about the presence of a road? Ideally, unambiguous measures, able to compare results of all segmentation techniques, should indicate the quality of the segmentation result. This measure should not only include geometry, but aspects like context as well.

Updating of the interpretation evidence
The candidate node has to be examined in a next step of the hypotheses hierarchy. Because we already found evidence for the presence of a fly-over, we will first examine if it is a fly-over. For this confirmation we need context information too. So recognized parts of the road network can guide further interpretation.
Future recognized objects may also influence present decisions. If road segments are found that cross the current road at the location of the gap, the evidence that there is a node of type fly-over increases.

5. CONCLUSIONS

Image interpretation of aerial images by computer is a highly complex task. The casestudy illustrates that even for one simple road segment in the database, a complex procedure is needed to verify its presence in the aerial photograph and to check whether its properties, such as width and curvature, have changed.
The problem is to bridge the gap between the image, which is a two-dimensional intensity array, and the object models.
A multitude of segmentation methods should be employed in an integrated way. In our opinion first more insight is needed into the performance of segmentation techniques on aerial images, before the image interpretation problem can be solved. A bottleneck is the lack of measures for the evaluation and comparison of the performance of segmentation techniques.
An inherent problem of interpretation is the integration of knowledge sources. Based on these knowledge sources, hypotheses should be constructed, tested and updated. In a multi-stage approach the parts of the image that have been examined influence the interpretation process. The evidence of previous interpreted objects should be updated, with progressing availability of context information.
Consequently, the computational burden of managing the interpretation process with its many feedback-loops is huge.
One of our present points of concerns is whether expert shells are suitable for managing the complexity of the interpretation process.

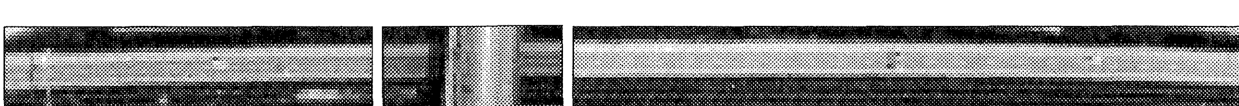

Fig.6 *The region of interest of fig.3 splitted in three parts*
a) candidate road segment; b) candidate node; c) candidate road segment.

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