VERIFICATION OF A METHODOLOGY FOR THE AUTOMATIC SCALE-DEPENDENT ADAPTATION OF OBJECT MODELS

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ABSTRACT:

A methodology for the automatic adaptation of object models consisting of parallel line-type objects parts to a lower image resolution was developed previously. This paper aims at the verification of this algorithm and describes the verification process. The verification is supposed to allow a statement whether the automatically adapted object models produce satisfying object extraction results and are as useful for image analysis in the lower resolution as the original model is in high resolution.
For this purpose, an example system was created comprising the automatic adaptation of a given object model for road extraction to several lower image resolutions as well as the implementation of the original and the adapted object models in a knowledge-based image interpretation system. The paper illustrates the results of the object extraction with the adapted object models and comments on the comparison of these results. At the end of the paper, conclusions concerning the success of the automatic scale-dependent adaptation algorithm are drawn from the verification results.

1. INTRODUCTION

Due to the varying appearance of landscape objects in different image resolutions, an already existing model for image analysis can usually not be used for the extraction of the same object in another resolution. Hence, several models need to be created for the extraction of a landscape object, although the information, how that object looks like in a lower resolution image is already implicitly contained in the model for the highest spatial resolution. This can be assumed, as objects can loose some details in lower resolution images, but usually no new details are added.

The automatic generation of image analysis models for the extraction of landscape objects in aerial and satellite images is a crucial issue of research, as it can reduce tedious manual work [Mayer04]. Methods for the automatic adaptation of image analysis models consisting of parallel line-type object parts to a lower image resolution were developed in order to facilitate the redundant work of object model creation for lower resolutions [Heller&Pakzad05]. A similar algorithm is known in cartography as model generalisation [Sester01]. Generalisation is carried out according to cartographic rules in order to adapt a symbolic appearance of objects in maps in different scales; the algorithm for model adaptation to be verified here, however, requires the prediction of the object's geometric and radiometric appearance in images of reduced resolution.

In the remainder of this paper, the image analysis models to be adapted are called "object models", while they not only describe the relations of the object parts among each other, but also their appearance in the image. According to the categorisation of models given in [Förstner93], the models adapted here integrate both the object model and the image model. The processed object models use the explicit type of representation of semantic networks. In order to enable an automatic adaptation, the object model to be adapted needs to fulfil certain requirements [Pakzad&Heller04]. The developed methods use for the prediction of the appearance of the object in a lower image resolution the concepts of linear scale-space theory, e.g. [Witkin86], [Lindeberg94]. The automatic algorithm for the scale-dependent adaptation of object models represents a new approach for the automatic creation of models in image analysis. Up to now, these methods have not been tested extensively on aerial image data and therefore the new adaptation algorithm could not yet be approved sufficiently. The work presented in this paper strives for the verification of the developed methodology.

In an example system an object model for the extraction of a dual carriageway in very high-resolution images is implemented in the knowledge-based image interpretation system GeoAIDA [Bückner02], [Pahl03]. The model is automatically adapted with the developed methods to three lower spatial resolutions. The adapted object models are also implemented in GeoAIDA and its extraction results are compared to the results, which were gained with the given object model for the high resolution. For the comparison aerial images of a suburban region are used.

Section 2 gives a short summary of the strategy and the methodology of the adaptation algorithm. The concept used here for the verification is described in section 3. The example system including the implementation of the example object model in GeoAIDA and three automatically adapted object models to lower resolutions is presented in section 4. Section 5 compares the extraction results of the original object model and the adapted object models. Conclusions from the results of the verification are derived in section 6.

2. STRATEGY AND METHODOLOGY FOR SCALE-DEPENDENT ADAPTATION

2.1 Strategy

The general strategy for the automatic adaptation of object models can be divided into three main steps that enable the separate scale-space analysis of object parts for the prediction of their scale behaviour while scale changes (cf. Fig.1).

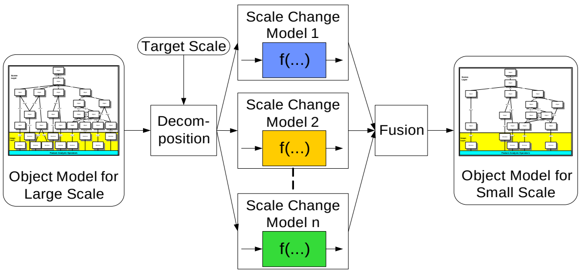


Figure 1. Strategy for Scale-Dependent Adaptation

With knowledge of the target scale, the original object model for high spatial resolution is at first decomposed into object parts with similar scale change behaviour and in neighbouring object parts that interfere each other's appearance in the coarser scale. These groups of object parts are then analyzed separately regarding their scale behaviour. Their appearance in the lower target resolution is predicted by so-called scale change models. At last, all predicted objects are composed back to a complete object model, suitable for the extraction of that object in images of the lower target resolution.

2.2 Methodology

The methodology to be verified here carries out the adaptation of a given object model created for a certain image resolution to a coarser resolution in an automatic algorithm. The automatic methods are based on linear scale-space theory, as the reduction of spatial resolution is a matter of scale change. The analysis is undertaken in scale-space to examine the appearance of object parts in the target resolution. The adaptation process takes into account discrete scale events, which may appear during scale change and affect the structure of the resulting semantic net. For parallel line-type object parts two scale events are relevant: Annihilation (disappearance of objects) and Merging (one or more objects merge into a single object). Besides the scale events, the scale change models automatically predict the resulting attribute values of the object parts in the target resolution as well, thereby adapting the description of the appearance of the object parts in the lower resolution image. The adapted attribute values serve then as new adjusted parameters for the feature extraction operators in the target resolution. For a detailed insight into the developed methods, please see [Heller&Pakzad05].

3. VERIFICATION CONCEPT

A verification of the new methods can decide on the success and usefulness of the developed adaptation algorithm. Thus, the verification method used here not only has to allow a statement on whether the extraction of the object in the respective lower resolution utilising the adapted object model is possible at all, but also on how well the prediction of the objects' appearance in the target resolution is done with the developed algorithm. As the adaptation process naturally changes the object model, a direct comparison of the given model with the adapted model is not reasonable. Rather the extraction results of several adapted object models gained in the respective lower resolutions with the extraction result of the original object model are considered here for verification.

The concept of the verification method applied here is depicted in Fig.2. With both the original model for the high resolution and the adapted object model for the lower resolution the image analysis is carried out on image data with corresponding spatial resolution. In order to ensure comparability of extraction results, it is reasonable to derive the image data utilised for the extraction in lower resolution from the same image scene in high resolution, which is simultaneously used for the extraction of the object with the given high-resolution object model. For this purpose, the image data of the high resolution are at first filtered with a Gaussian low-pass filter in order to avoid aliasing and subsequently down-sampled to the desired spatial resolution by bilinear transformation. The obtained extraction results in both resolutions are then compared to each other. To gain better insight about possible insufficiencies of the automatic adaptation process, the verification is here carried out by incorporating both the whole object and the object part results.

Completeness and correctness regarding the extraction output are used here in the comparison process as a measure for the success of the adaptation methodology. The result of the extraction applying the given object model in the high resolution serves as reference data set, i.e. this extraction outcome represents 100% for both completeness and correctness. By comparing the results of the extraction with the automatically adapted object models in the corresponding image data to the reference data, only the quality of the adaptation algorithm is evaluated. In contrast, the image analysis capability of the adapted object models in regard to an extraction reference set created manually from an aerial image is not subject of this study. The quality of the target object extraction, however, is clearly specified by the high resolution object model itself, which is not verified here.

Because the structure of the object model can change in the adaptation algorithm due to the occurrence of scale-space events, the comparison including object parts is not straight forward. The comparison method of the extraction results in different resolutions needs to consider possible scale events. Generally, the occurred difference can have three main origins. The first is the occurrence of scale events, which can easily be explained by a difference in the structure of the object models, as the scale event should also have been predicted in the adaptation process and therefore be inherent in the adapted object model for the low resolution. Another reason for an

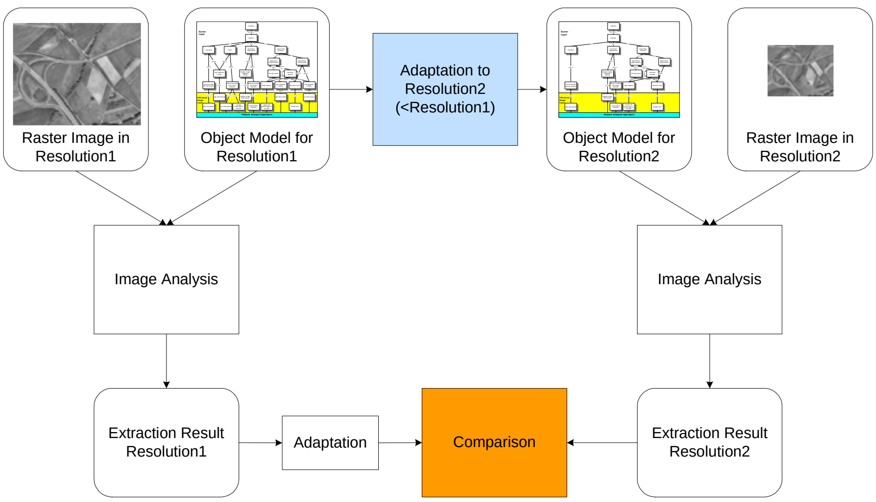


Figure 2. Concept of Verification

extraction difference could be the inconsistent performance of the feature extraction operators that are assigned to the object parts. The feature extraction operators carry out the extraction of the object parts and could prove less successful or even fail completely in the lower resolution. In a third scenario, the adaptation of the object model to the coarser scale is incorrect. In this case, the automatic adaptation methodology is erroneous. It is then tried to enhance the quality of the adaptation algorithm by searching for the problem in the methodology and resolve it to obtain a sufficient adaptation result. The verification is then repeated. With this loop the adaptation algorithm is improved.

4. EXAMPLE SYSTEM

4.1 Input Data

4.1.1 Image Data

For the verification process high-resolution aerial image data of a suburban region near Hanover, Germany were used. The images were digitised to 0.033m spatial resolution. In order to ease the verification process and to make its documentation more clear, the images were transformed from colour (RGB) to grey value images. Fig.3 displays the three test images that have been used for the verification. Whereas the first image is relatively simple, the other two images display a curved road and contain disturbances that hinder the extraction of the object parts, e.g. shadows and a non-permanent road work marking, which is not contained in the given example object model as a neighbouring line in the vicinity.

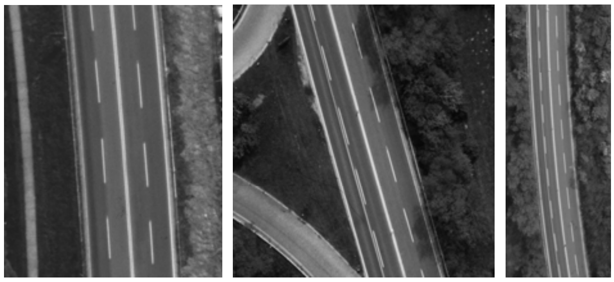


Figure 3. Example Images in 0.033m/pel

4.1.2 Example Road Model

The example object model for the high resolution was created manually for a dual carriageway in images of 0.03-0.04m resolution. Fig.4 displays the given original object model for the high resolution, serving as a starting point for the automatic adaptation. The semantic net is composed of the roadway itself and the road markings, forming nodes, which are part of the road. The uppermost node “roadway” is modelled here as a continuous stripe with a certain grey value and extent, i.e. width of the line-type object. The road markings are either of object type periodic stripe or continuous stripe. A periodic object describes lane markings, which appear as dashed lines in the image. The nodes not only contain the respective object type, but also values for the attributes grey value, extent and periodicity. The specification of the spatial relations and the distances between the object parts are essential for the scale-dependent adaptation process. The distance *d* corresponds to the width of a single lane. All nodes of the net are connected to appropriate feature extraction operators.

The original example object model was adapted with the automatic algorithm to be verified to a spatial resolution of 0.10m. This scale change corresponds to a scale parameter σ=1.0. In the adaptation a scale event was predicted – the Merging of the two central continuous line markings to a single line. Although in the grey value profile there are still two

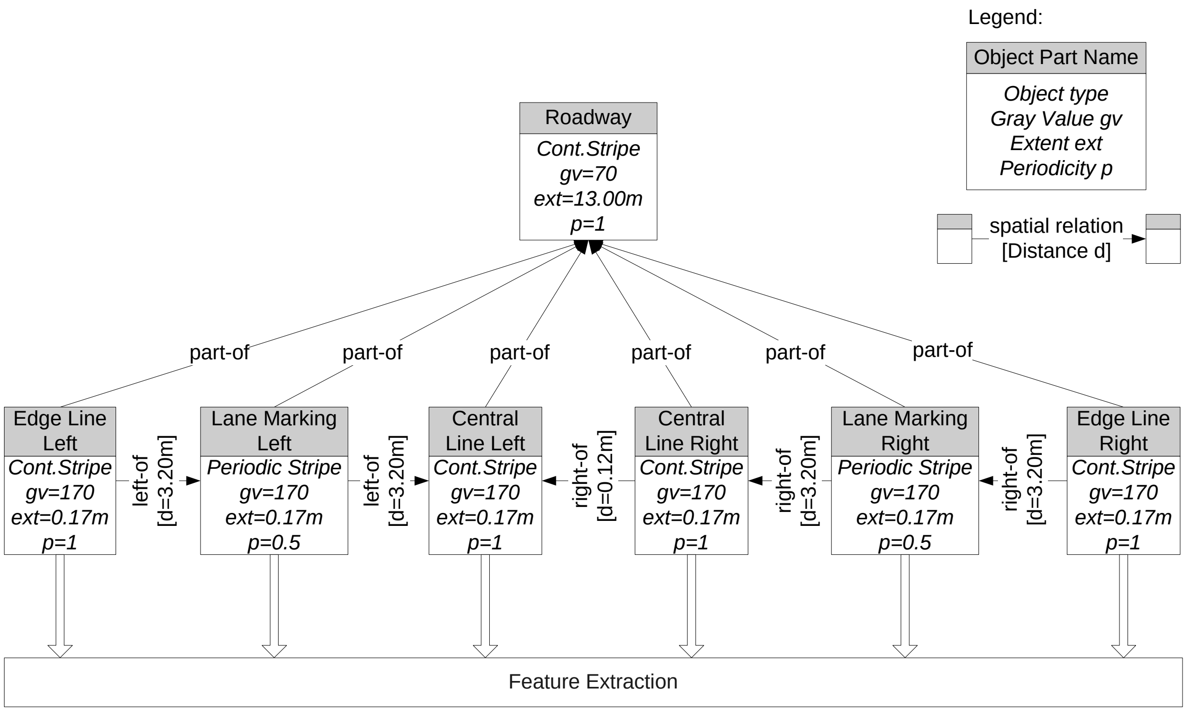


Figure 4. Original Object Model for Dual Carriageway in 0.03m/pel

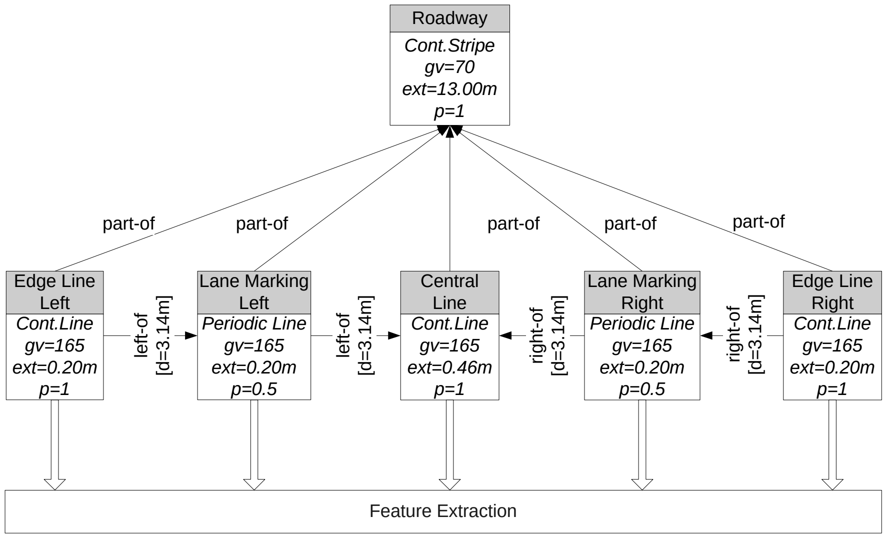
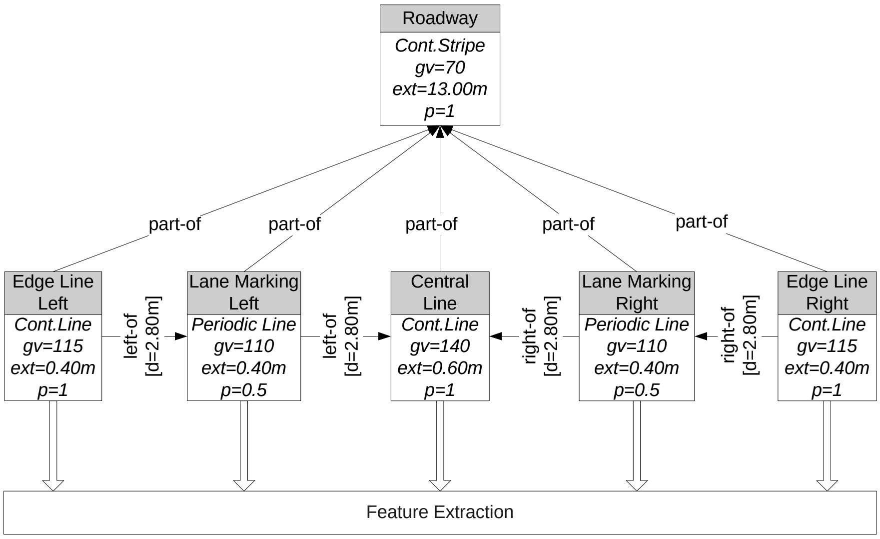


Figure 5. Adapted Object Model for Dual Carriageway 0.10m/pel



distinct maxima present, these two adjacent lines cannot be distinguished reliably from each other anymore in an image resolution of 0.10m by the line extraction operator. Furthermore, the values for the attributes are adjusted due to the slightly different appearance of the object parts (road markings) whose type now changed from stripes to lines in the lower resolution image. The lines appear wider and with less contrast in the images of the lower resolution. The resulting object model for the extraction of the example road in 0.10m resolution images is depicted in Fig.5.

In the scale-dependent adaptation to 0.20m no further scale event were confirmed. However, the central lines now exhibit a definite Merging with only a single maximum in the grey value profile left. The attribute values for grey value and extent of the object parts are adjusted here as well (cf. Fig.6).

As a last target resolution for the verification 1.00m was chosen. For this resolution the adaptation algorithm predicted the failure of the operator for lane markings, resulting in another scale event – the Annihilation of the lane markings. The structure of the semantic net has been altered here significantly with only three extractable road markings left, as can be seen in Fig.7.

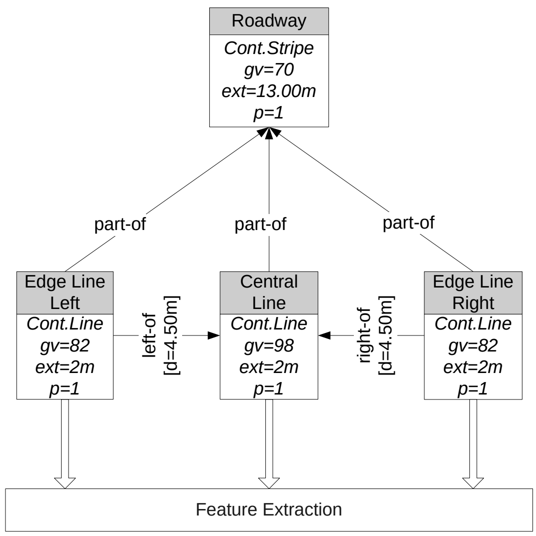


Figure 7. Adapted Object Model for Dual Carriageway 1.00m/pel

4.2 Concept of GeoAIDA

The knowledge-based image interpretation system GeoAIDA was developed at the Institute of Communication Theory and Signal Processing (TNT) at the University of Hannover and represents a tool for image analysis incorporating a priori knowledge in form of semantic nets [Bückner02]. Hypotheses for the existence of the object parts in the semantic net are generated and evaluated in the extraction process. GeoAIDA applies Top-Down- and Bottom-Up-operators. After generating the hypotheses, for each object part the corresponding Top-Down-operator is called, extracting from the input image data the respective object part by image processing algorithms. The output of the Top-Down-operators is then evaluated and grouped to superior objects by the Bottom-Up-operators. For verified hypotheses an instance net with label images for the corresponding instance nodes is created.

4.3 Implementation of the example object model

In the example system the Top-Down-operators carry out the extraction of the road markings, which are modelled as object parts in the example road model. The operators extract edge lines and central lines as continuous lines and lane markings as dashed lines. The operators use the line extraction algorithm of Steger [Steger98], followed by the evaluation and fusion of lines according to [Wiedemann02]. The algorithm of Wiedemann was adapted to the special requirements of the extraction of road markings in high-resolution images [Schramm05]. Ingoing parameters for the road markings extraction are width and contrast of the lines in the image. The operators were designed very flexible in regard to the setting of the parameters, allowing the adjustment of parameters in accordance with varying width and contrast of the markings in different image resolutions.

The Bottom-Up-operators group the extracted lines and evaluate the instances concerning the hypotheses from the semantic net. At first the operators select from the results of the Top-Down-operators those lines with the appropriate attribute values that fit to the ones assigned in the nodes of the semantic net. The lines are then tested for their spatial relations, also considering their distances to each other. Instances fulfilling all the conditions of the relations of the object parts determined in the semantic net are subsequently grouped to a superior object. This superior object is grouped again with appropriate line instances, if the spatial relation to that line is satisfying. This grouping is repeated until all hypotheses for the object parts (road markings) are evaluated. If all hypotheses were accepted, the extraction of the road in the examined image is successful and GeoAIDA creates the label images with the instance nodes.

5. RESULTS

5.1 Reference Data Set 0.033m

The extraction result obtained with the original object model in the cut-out of the example image set serves as reference for the verification of the adaptation algorithm in the example system.
The extraction of all relevant road markings with the Top-Down operators in the example image was successful. All road markings were grouped by the Bottom-Up operators according to the spatial relations assigned in the given object model for 0.033m image resolution. Fig.8 depicts the result of the object extraction with the road markings operators.

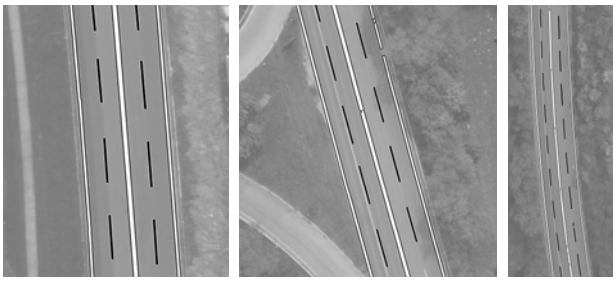


Figure 8. Extraction Results in 0.033m/pel – Reference (white: edge lines, black: lane markings)

5.2 Extraction Results 0.10m

The extraction of the road markings in 0.10m resolution was carried out with adjusted parameter values for contrast and line width taken from the adapted object model. All relevant road markings were found and the grouping was successful. In comparison to the reference data set all object parts were extracted correctly, taking into account the scale event Merging of the central line. The central line was extracted with the edge line operator, but with a different line width parameter taken from the adapted model. The correctness achieved 100% for this target resolution. In contrast, the extraction of the right edge line was not complete in the second image in shadowed image regions.

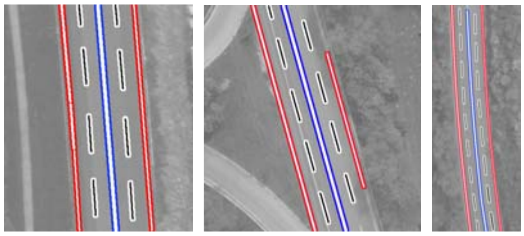


Figure 9. Extraction Results for 0.10m/pel (white/blue: central line, white/red: edge lines, black: lane markings)

5.3 Extraction Results 0.20m

In 0.20m resolution not all the object parts could be extracted 100% completely and correctly with the predicted attributes for contrast and width. The operators had problems in shadow regions and for the left dashed lane marking with the adjacent continuous road work marking in the second and third test image. However, the grouping of the road markings was still successful with the adapted distances between the object parts.

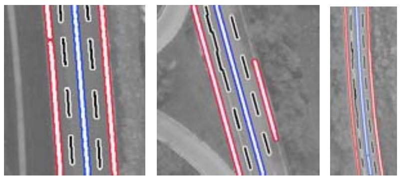


Figure 10. Extraction Results for 0.20m/pel

5.4 Extraction Results 1.00m

For a resolution of 1.00m the predicted entire failure of the lane marking operator is confirmed, although there is still a dashed line with small contrast in the image existent. This Annihilation was predicted correctly by the adaptation algorithm. Due to shadows and low contrast the operator for continuous lines is not successful for all the edge lines in the first two example images (cf. Fig.11). Therefore, not all hypotheses could be verified by the Bottom-Up operators and subsequently the object dual carriageway could not be extracted successfully in these two example images with the feature extraction operators used for a resolution of 1.00m/pel. In the third image all remaining lines were extracted, thereby proving the adaptation algorithm also for 1.00m to be correct.

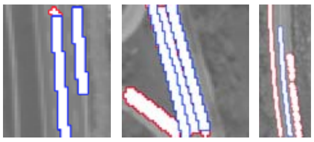


Figure 11. Extraction Results for 1.00m/pel (enlarged)

5.5 Comparison to high resolution extraction results

For the comparison of the extraction results of the lower image resolutions the difference to the reference data set is of interest. In order to estimate the quality of the automatic adaptation the percentage of the difference to the reference set is determined. Table 1 reflects the completeness and correctness values for all object parts in the adapted object model for the three target resolutions. Due to degraded contrast and context objects the completeness suffered in some image regions. The insufficient extraction result regarding completeness for the third examined target resolution of 1.00m can be accounted to the limit of the usability range of the applied feature extraction operators, which can be reduced by disturbing influences, such as shadows or insufficient contrast. This usability range therefore simultaneously defines the scale change limit for the adaptability of the given object model with its assigned feature extraction operators.

	0.10m	**0.20m**	**1.00m**
Completeness	97%	96%	60%
Correctness	100%	90%	100%

Table 1. Completeness and Correctness of extraction results for object parts with adapted object models in target resolutions

6. CONCLUSIONS AND OUTLOOK

A method for the verification of a previously developed algorithm for the automatic adaptation of object models was presented, enabling the assessment of the success of the developed algorithm. The results of the verification lead to the conclusion that an automatic scale-dependent adaptation exploiting linear scale-space theory is generally possible. The prediction of scale events of object parts occurring during scale change could be confirmed being correct by the verification process. In the verification process the tested algorithm can be improved, correcting unforeseen shortcomings.

The verification results also revealed the sensitivity of the adaptation algorithm to the assigned feature extraction operators. The assigned feature extraction operators in the original object model should be easily adaptable to another resolution by parameters corresponding to the attributes in the nodes of the adapted object model. Otherwise, the operators might fail already for a relatively small change in image resolution. This flexibility is desirable in order to enlarge the range of image resolution, for which the adaptation with the examined methodology will be successful. The performance of the operators can also be degraded or even lead to a complete failure to extract the object due to disturbances in the images, such as shadow or local context objects. This limitation could be overcome by extending the adaptation algorithm in regard to the incorporation of local context in the adaptation process. This algorithm extension is therefore a goal for the near future.

For further future tasks, a test of the algorithm for satellite image resolution (up to 5m) is intended by using the feature extraction operators of the continuous road markings for the extraction of the roadway, as roads possess the same object type in satellite images.

7. ACKNOWLEDGEMENTS

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