MULTI-SENSORAL DATA PROCESSING FOR URBAN LANDSCAPE MODELLING: NEW MERITS AND NEW PROBLEMS

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ABSTRACT:

Multi-sensor remote sensing systems have been developed for a simultaneous acquisition of image and elevation data. However, reliable automatical processing methods – in particular for the interpretation of multi-sensoral data with high geometrical resolutions – are still at a development stage and by no means operational yet. In this context it will be shown how the increased potential of multi-sensor systems can be used to extract and process additional features for the purpose of urban landscape modelling. But not only these new merits, also new problems with the extended feature sets will be discussed – in particular the increased efforts to generate conceptual and logical object models which is also an important factor leading to a limited operationality. Finally, alternative conceptual solutions will be addressed that follow the goal to overcome the described dilemma.

1 INTRODUCTION

Remote sensing data are an important information source for urban landscape modelling. As a reaction to the limitations of the available data, in the last ten years the focus within the remote sensing community was laid on the **development of sensors** with advanced capabilities with respect to their geometrical, spectral, radiometrical and temporal resolutions. Respective examples are space-borne sensors like Ikonos and QuickBird, or digital air-borne systems like the Digital Modular Camera (DMC; Z/I-Imaging), the Airborne Digital Sensor (ADS40, Leica Geosystems) or the High Resolution Stereo-Camera (HRSC-A, DLR Berlin). Furthermore multi-sensor systems have been created for a simultaneous acquisition of image and elevation data. Examples for this species are the FALCON system (TopoSys), or the possible combinations of the ADS40 with the laser scanner ALS40 or of the laser scanner ALTM-2050 (Optech) with a CCD camera.

However, it has to be stated that reliable **automatical processing methods** – in particular for the interpretation of multi-sensoral data with high geometrical resolutions – are still at a development stage and by no means operational yet. Vice versa, it can be concluded that a large portion of the potential of remote sensing sensors in contrast to the human sensing system (e.g., larger spectral bandwidth, spectral separability, acquisition of precise elevation values) is not properly utilised in the subsequent automatic scene interpretation process.

In the context of these deficiencies this paper follows three major **goals**:

1. It will be shown how the increased potential of multi-sensor systems can be used to *extract and process additional features* for the purpose of urban landscape modelling - based on an extended region-based processing methodology (chapter 2).
2. But not only these new merits, also new problems with the extended feature sets will be discussed – in particular the increased efforts to generate *conceptual and logical object models* which again is a factor leading to a limited operationality (chapter 3).
3. In order to overcome the described dilemma alternative conceptual solutions will be addressed which are mainly based on a combination of conventional algorithmic with heuristic approaches (chapter 4).

2 NEW MERITS

The simultaneous acquisition of image and elevation data offers the possibility to extract an *increased number of features*, and with that to improve the interpretation reliability from a statistical point of view. Based on a multi-sensoral data set (section 2.1) and a general extended region-based processing methodology (section 2.2) we will demonstrate respective examples (section 2.3).

2.1 Exemplary data set

During the last couple of years, laser scanning systems have reached maturity due to the enhanced performance of GPS/IMU solutions for capturing orientation data of the associated moving platforms. Last year the TopoSys company released their airborne FALCON system which not only delivers laser scanning elevations but simultaneously acquires multi-spectral imagery. The laser scanner operates with a glass fibre array producing a parallel acquisition pattern. First and last pulse elevation data with a height accuracy of about ± 0.2 m are delivered in a raster of $(0.5\ m)^2$ or $(1.0\ m)^2$, respectively, having a swath width of 250 m for a flying altitude of 1000 m. The imaging sensor consisting of a line array scanner produces four bands in the visible and near infrared spectrum with a ground

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pixel size of 0.5 m at a radiometric resolution of 11 bit (TopoSys, 2003).

In the following we will use a scene covering a part of the City of Ravensburg (Germany) showing both man-made and natural objects (refer to figure 1). Goal of our scene interpretation will be the extraction of the object classes “buildings”, “roads” (including paths and paved areas), “meadows”, and “bushes/trees”.

Figure 1. Part of the multi-sensoral data set: Multi-spectral imagery (top, coverage approx. 400 m x 300 m) and perspective view after draping onto the Digital Surface Model (bottom).

2.2 General processing methodology

The proposed increased amount of features which are of heterogeneous types and are based on high spatial resolutions demand for a flexible, *integrative processing method*. For that reason we apply a *multi-scale* and hierarchical method which performs a *segmentation* prior to the classification step and uses knowledge as defined in a conceptual model (figure 2). For a more detailed discussion also refer to Schiewe (2003).

The method starts with an incremental upscaling of the given remotely sensed data using the Fractal Net Evolution Approach (FNEA; Baatz & Schäpe, 2000) which leads to a segmentation pyramid. Because different objects can be delineated from the others best by using different features we introduce object class specific segmentation parameters (e.g., elevation curvatures for buildings, NDVI for roads) which leads not only to one but multiple segmentation pyramids.

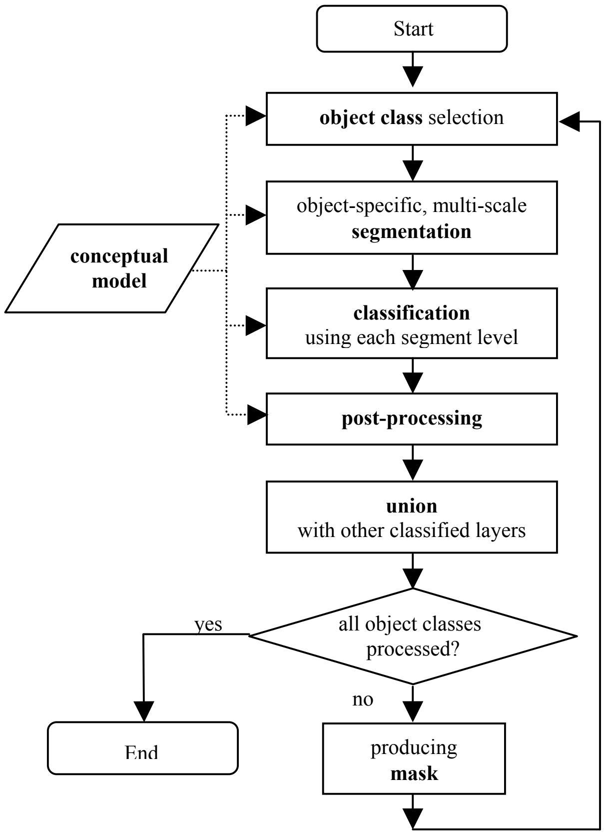

Figure 2. Outline of hybrid and multi-scale approach.

Next an object class specific classification takes places at each segmentation stage, going from fine to coarse levels. The object hypothesis is verified or falsified by comparing the actual segment attributes with those as defined in the conceptual model. Particularly, object heights, curvatures, NDVIs and areas are used as features. The classified regions are then kept for the next level.

However, we still have to cope with the problem that the aggregation of small segments (for example: single buildings) to larger regions (for example: building blocks) is still possible at one of the next segmentation levels. Hence, we not only classify segments in a "positive" but also in a "negative" manner, i.e. we also define segments which definitely do *not* belong to this class. With that a "positive" classification at a higher level of aggregation is only possible, if no "negative" classification is attached to one of its sub segments.

After each classification an object specific post-processing by means of standard image processing operations is performed. For instance, in case of the buildings islands within the interior (e.g., due to small bays) are removed by a Closing operation.

Finally, it has to be stated that the support of an existing GIS database is able to optimise the approach even more by determining the parameters for both the conceptual model as well as the post-processing operations (e.g., see Ehlers et al., 2002). This can be realised in an a priori manner ("reverse engineering") or ad hoc, i.e. through the immediate integration of feature vectors of detected objects during the classifications process.

2.3 Feature extraction

For the given typical data set we can state that due to the variance of existing objects conventional planar form features like compactness or elongatedness are of minor significance compared to spectral properties (in particular, the NDVI) and to three-dimensional geometrical features as derived from the laser scanning data. In this context, we propose that additional and more complex scene features, which consider actual *functional* attributes and can lead to a better separability, should be taken into account. In the following we will present two examples in the course of urban landscape modelling, namely the extraction of building walls as well as of narrow but elongated, possibly parallel area structures like hedges or furrows.

From first and last pulse laser scanning data elevation gradients, curvatures and textures can be derived which other than the object heights themselves have been proven to be reliable indicators for certain object classes. For instance, very high elevation curvatures are able to identify building walls in contrast to other objects that stand clearly above the terrain surface (like trees or groups of trees). Of course, additional post-processing operations have to be applied: The walls are only accepted as such if an interior region is next to them. Furthermore, the wall segments are changed to a narrow and complete outline. Figure 3 illustrates the outlined classification and post-processing steps.

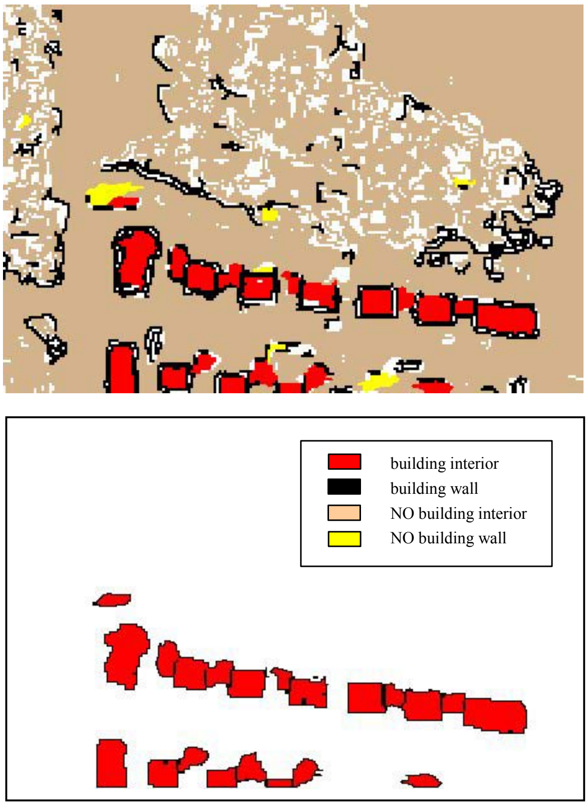

Figure 3. Classification of building elements (top) and result after post-processing (bottom).

In general, multi-spectral imagery and derived features like the NDVI or band-specific textures are well suited for modelling tasks, for example for differentiating between vegetated and non-vegetated areas within urban landscapes. Furthermore, narrow but elongated, possibly parallel area structures like hedges or furrows can be extracted after incorporating extended algorithms. Figure 4 demonstrates that for the shown area under cultivation the conventional detection feature of the mean NDVI is not suited due to internal, narrow non-vegetated areas.

Also the results of texture filtering or edge extraction are not able to detect and describe these area elements properly. Thus, after detecting lines (instead of diffuse edges) and extracting parallel patterns of the cultivation area (based on the parameters elongatedness and main direction) we perform a watershed algorithm for segmentation purposes. We do not apply a region growing method because homogeneous segments are hardly to detect by this type due to their narrowness.

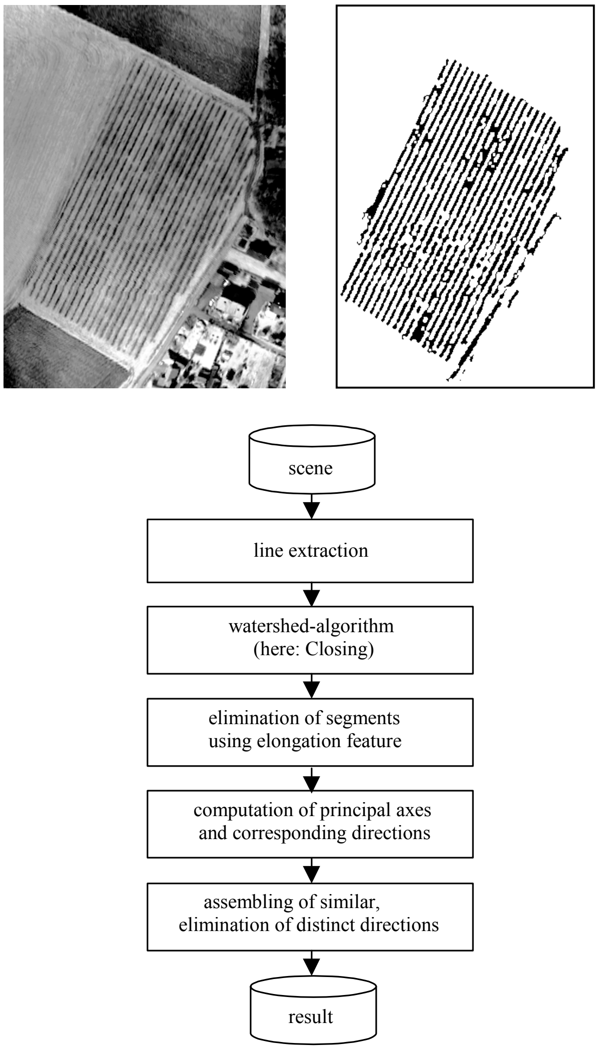

Figure 4. Simple algorithm (bottom) for the extraction of area structures (top right) from given imagery (top left: near IR channel, coverage approx. 160 m x 420 m).

Finally, it has to be mentioned that beyond multi-spectral and laser scanning data the reflected *intensities* of the laser beam give an additional promising information source. Our first experiences have shown that these data can serve for a certain overview but due to the not fully understood special characteristics of the active sensor reflections (like the superimposition with other reflected energy, the multi-echoing effect, or the dependence on beam travelling distances) a detailed classification is not possible yet.

3 NEW PROBLEMS

The availability of high resolution and multi-sensor data and with that the extended set of derived features do not only lead to new merits and chances as outlined before, but also to new problems. After a general overview (section 3.1) we concentrate on the increased efforts to generate conceptual and logical object models which again is a factor leading to a limited operationality (section 3.2).

3.1 General problem overview

It is well known that new approaches are necessary which enable both the processing of high resolution data and the integration of various multi-sensor or multi-source input. However, new problems arise at all stages (compare fig. 2) of the resulting algorithm.

The **segmentation** prior the conventional classification is generally accepted as a necessary processing step (Blaschke, 2000). However, it has to be stated that fully automatic, reliable and transferable solutions for creating homogeneous regions are not available yet. A key problem in the context of topographic and urban modelling is that different objects and object classes can be best delineated at different spatial scales. Hence, the choice of segmentation parameters (e.g., the grade of generalisation) as well as the evaluation of the derived regions is a major problem which is solved by additional and time consuming visual inspections as well as iterative repetitions of the segmentation step (Schiewe et al., 2001).

In section 2.2 we have presented a hybrid approach that shall overcome some of these problems by a close integration of the segmentation and classification steps. Such a hybrid procedure also implies an integration of **conceptual object models**. But the desire and necessity of integrating more features into the classification process also leads to the fact, that for decision making purposes a more complex object modelling on a conceptual as well as on a logical level becomes necessary. In the following section 3.2 we will demonstrate the resulting increased efforts in more detail.

Finally, **classification** processes are seen as well defined standard methods. However, a couple of deficiencies have to be mentioned. In particular, there are uncertainties and missing objective proofs for the selection of a certain approach (e.g., refer to Cheng, 2002, or Fisher, 2000). In this context, we propose that *fuzzy logic* classification approaches will become more and more dominant because there are several reasons for introducing partial rather than crisp memberships in this context: On the one hand, the descriptions of real phenomena are neither geometrically sharp nor certain. On the other hand, the limited spatial sampling rates and measurement errors (the latter being mostly unknown) also lead to indeterminate boundaries and the necessity of flexible descriptions.

3.2 Example

As already mentioned above, for decision making purposes a more complex object modelling on a conceptual as well as on a logical level becomes necessary, if multi-sensoral data are introduced. This modelling means that not only the objects under consideration but also their specific features with possible feature value ranges, their relations among each other as well as appropriate methods to extract and process these information have to be defined.

Even in the first step of conceptual modelling it becomes obvious that there is not only an extended amount of variables and relations but also a lack of formalisation standards for some object types (like for the numerical description of trees, groups of trees, or forests). With respect to the extent of the conceptual model, figure 5 gives an impression by showing just a small portion of the entire model for the exemplary interpretation task as outlined in section 2.2. It has to be noted that this model has already been reduced by a selection of significant features out of the entire feature set.

Although there are some systems available for the design and implementation of conceptual models (e.g., geoAIDA; Bückner et al., 2001), all approaches (like semantical or neuronal nets) have in common that their generation and update is very time and cost consuming. Furthermore, their transfer to other applications is rather doubtful. In conclusion it can be stated that the increased modelling efforts seem not be justified from an economical point of view except for multiple applications (Baltsavias & Hahn, 2000). Also the use of knowledge from existing GIS databases yields only marginal advantages and leads to a significant reduction of costs only in the case of long term and multiple applications (Konecny, 1995).

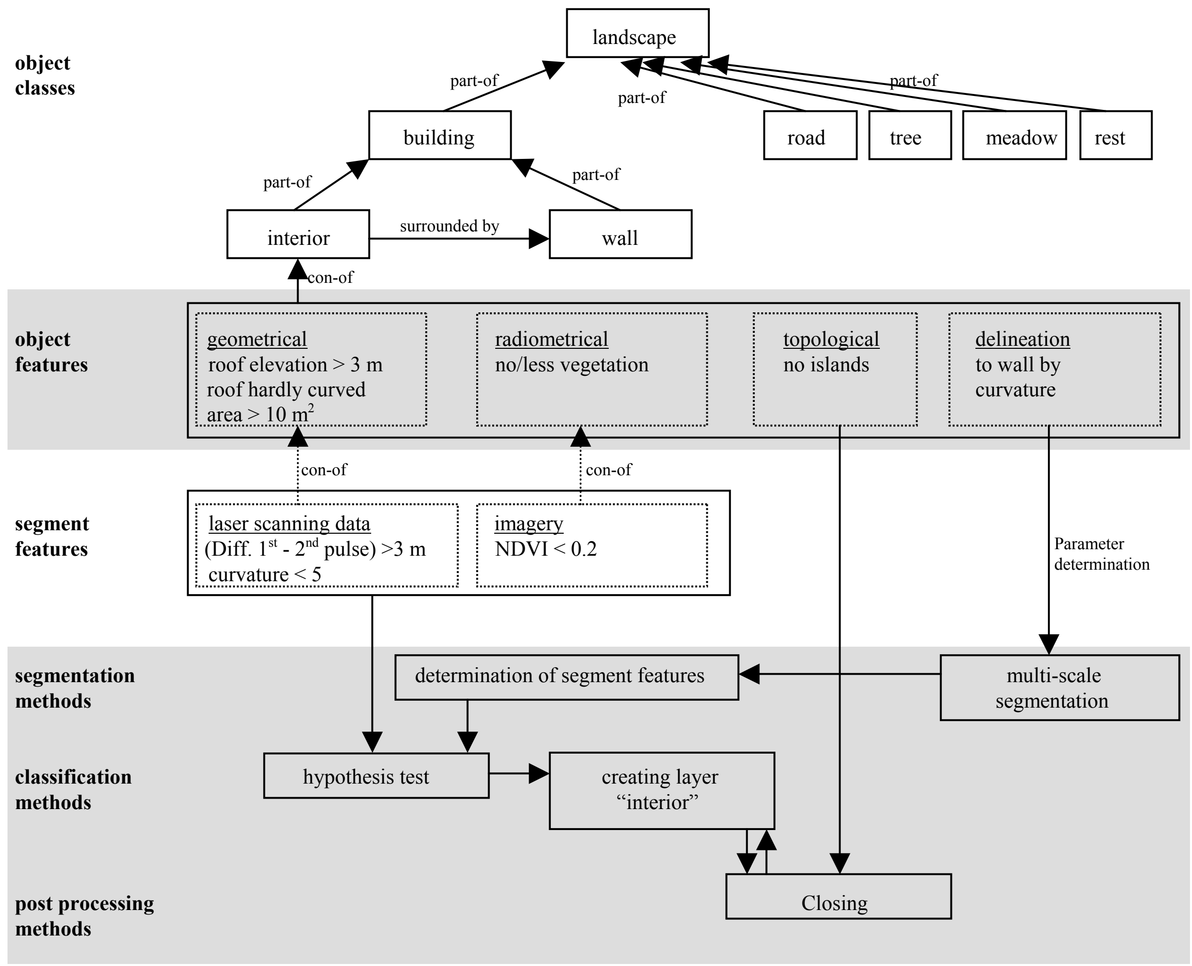

Figure 5. Portion of the conceptual model for the exemplary interpretation task

4 CONCLUSIONS

We have demonstrated the increased but yet not fully exploited potential of multi-sensor systems in terms of extracting and processing additional features for the purpose of urban landscape modelling. On the other hand we have also stressed new problems, in particular the missing automatisation of the necessary segmentation step and the increased efforts to formalise the very complex conceptual and logical object models – both aspects leading to a limited operationality and user acceptance.

Based on the fact that practical algorithmic solutions for the above described formalisation and complexity problem are not at the horizon, we propose a stronger combination of algorithmic with *heuristic approaches*. The latter can be compared with the methods as applied by human operators who neither use all available features nor compute all class memberships which leads to sub-optimal classification results only. Heuristics can be integrated at various processing levels:

- Heuristic decisions are necessary for the *selection of features* which are significant for the separation of one desired object (class) against others (as already applied with the conceptual model shown in figure 5).
- The representation of knowledge can be based upon *heuristic decision trees, tables or diagnosis scores* in order to reduce the complexity of the set of features, object classes and relations between them. The mentioned approaches are able to define a selection of features as well as a processing sequence, and also to consider uncertain or not existing feature values.
- Based on this heuristic classification or search methods (like Greeedy-, A*-, WA*-search, hill climbing) can be applied.

Finally, the entire approach has also to incorporate some loop or feedback mechanisms between the feature extraction, segmentation and classification steps (as demonstrated for the latter two in section 2.2). Based on this an optimisation through an objective, numerical evaluation of selected features can be applied.

5 ACKNOWLEDGEMENTS

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