TOWARD AN INTEGRATED SOLUTION FOR AN OPTIMIZED VECTOR DATABASE UPDATING PROCESS

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Working Group IV/3

KEY WORDS: Revision**,** Spatial Databases**,** Automation

ABSTRACT

The requirement for maintaining up-to-date spatial data originates both from the end-user and from the information provider, since inability to do so may result in reluctance to utilize the data. Maintaining up-to-date spatial data may be performed either by completely remapping the area of interest (a global strategy) or by a local updating cycle, in which limited areas ("patches") in the existing data set are updated according to need (a local strategy). When implementing the local strategy, two prerequisites must be fulfilled. The first is the ability to reliably detect discrepancies ("change detection") between an existing vector data set and up-to-date aerial imagery, which is considered a common source of up-to-date information. It is assumed that since a comparison between up-to-date raster data and existing vector data is required, feature extraction techniques that require some degree of human intervention would be implicated. Hence, optimization of this task may be achieved by minimizing the amount of extracted features. A second prerequisite involves the ability to optimize the integration of the existing and the up-to-date data sets, while upgrading the existing data set whenever possible. Current data integration procedures are based on transforming the up-to-date data into the existing data set. In order to maintain the internal consistency of the existing data set, the up-to-date data is constrained by the existing data during this integration. Nevertheless, the existing data may be of lower accuracy than the up-to-date data, thus it may not be justified to constrain the up-to-date data using the existing data. Hence, an optimized integration of the two data sources must be based on the accuracy of each data set. In this contribution, which summarizes an on-going research, an attempt is made to address these questions, and solutions for these questions are discussed.

1 INTRODUCTION

Keeping vector spatial data up-to-date is a continuous campaign against time and change. Within it, an arsenal of updating strategies and tools is employed in order to keep the spatial data at hand as close as possible to the real situation on the ground, so that the temporal accuracy of the data would be retained. A defeat in this campaign may result in reluctance by end-users to utilize the data, and the entire effort and resources invested in obtaining and maintaining it will ultimately be lost.

The campaign can be conducted either on a global scale, where the entire data set is replaced by new and up-to-date data, or on a local scale, where the existing data set is updated locally whenever changes are detected. The main drawback of a global scale updating is its duration and the resources required for its implementation. Current available spatial data sources, such as field surveying, aerial photogrammetry, or digitizing, require lengthy and labor-intensive processing procedures, during which changes might occur. Although fully automated feature extraction techniques may reduce the need for such resources when using photogrammetry as a data source, available techniques today are not always robust and still require considerable human intervention (Newby, 1996). These drawbacks lead to the conclusion that local updating strategies should provide a better solution since they eliminate the need to remap the entire interest area, and instead only areas affected by change should be remapped. Hence, the updating cycle can be significantly shortened. It is important to note that when large urban areas are to be remapped, aerial photogrammetry seems to be the most expeditious and cost efficient data source for updating purposes (Agouris and Stefanidis, 1996).

The implementation of the local updating strategy is not straightforward due to several critical prerequisites. The first prerequisite is the ability to perform a "reconnaissance of changes". Since in most cases there is no prior knowledge indicating where changes had occurred, applying a local updating strategy requires a *change detection* procedure, which will point out interest areas and guide the updating process. This is usually done by a human operator, using a superimposition technique, where one of the data sources is overlaid on top of the other data source, and manual comparison is performed (Newby, 1996). Such a comparison is straightforward only when both data sources share the same scale, accuracy, and thematic nature (Campbell, 1997). When this is not the case, the change detection process is prolonged due to the inability of the human operator to directly compare the data sources.

Assuming aerial photogrammetry is the source for new data, changes in vector data can be detected in object space as well as in image space. An example of image space usage can be found in Baumgratner et al. (1996), where the detection of new roads is accomplished by transforming existing roads into image space, followed by a rule-based detection of new roads. Hence, the existing data is used as a tool for narrowing down the search area for new roads. An example of the use of object space can be found in Yew et al. (1996), in which building corners are detected and mapped as a first step, followed by transformation of the new vector data into the existing data for comparison and detection of changes. Another example of the use of 3D object space for change detection is the utilization of DEM data, as described by Ramirez (1997). In this work two or more DEMs from different epochs are compared and possible changes are detected when discrepancies are found. This information is then combined with other change indicators in order to achieve more reliable change detection. It is important to note that although adequate DEM data from several epochs may not be readily available today, the use of airborne laser scanners is becoming a dominant source of high resolution DSM data that may be utilized for change detection purposes (Murakami et al., 1999).

A second prerequisite of the local strategy relates to the ability to incorporate the new data into the existing data set. Since in the local strategy data is collected only in areas where change was detected, the actual updating process of the existing data takes place when the new data is combined with the existing data set, resulting in a new up-to-date data set. The process of combining the two data sets usually involves a transformation of the up-to-date data into the existing data set, using a variety of transformations (Demirkensen and Schaffrin, 1996), (Greenfeld, 1997), (Tsai and Lee, 1998). During such transformations the existing data set is assumed to be the reference, an assumption that helps to maintain the internal integrity of the existing data set. Again, the transformation can be applied either globally, where the entire new data set is transformed as a whole, or locally, where each region of the new data is transformed separately. In many cases, applying a global transformation may produce inconsistencies in the transformed data because of the different error characteristics (such as error type and magnitude) in each region of the data set (Hebblethwaite, 1989). A solution can be found by dividing the data to be transformed into subregions and applying a different transformation for each region, in conjunction with the appropriate geometric constraints (Gabay, 1995), (Fava et al., 1990). A different approach, which utilizes influence regions for the determination of transformation parameters, has been proposed by Doytsher and Gelbman (1995).

Although the transformation procedures described may successfully incorporate the new data into the existing data set while insuring geometrical consistency, the question of the accuracy of both data sets is not fully addressed. Due to various reasons such as the continuous improvements in surveying equipment and practice, or poor quality of the existing data, the up-to-date data may be of higher accuracy than the existing data set. In these cases, using the existing data set as a reference during the transformation is not fully justified. Furthermore, such an approach is likely to introduce distortions into the new data during the transformation process, resulting in its degradation. An attempt to employ weighting during the estimation process of the transformation parameters would not necessarily provide a satisfactory solution since the accuracy relations between the data sets are unknown. Hence, knowledge about accuracy relations between the new data and the existing data sets is an essential prerequisite. Such information would also provide the ability to use fragments of the new data set that were not affected by change as additional observations for *upgrading* the corresponding fragments in the existing data set.

The problems and potential pitfalls of current updating procedures outlined in the preceding emphasize the need for an integrated solution for updating existing spatial data sets. In order to ensure both the effectiveness and the completeness of such a solution, it should provide the necessary tools for the entire updating cycle, as well as having the following characteristics:

- ***Minimizing the amount of up-to-date data extracted for the updating process***. As photogrammetry is a primary source of up-to-date vector data, extracting features manually from aerial photographs is laborious and time consuming. This calls for techniques that will reduce the amount of data extracted by focusing only on areas affected by change.

- ***Robust and highly automated change detection***. Current change detection algorithms do not match the reliability of an experienced human operator. In many cases they are applicable to specific data types, and require particular data that is not readily available in most databases. Hence, a closer insight into how a human operator detects changes may lead toward more reliable and comprehensive change detection algorithms.

- ***Optimizing the integration of the new and the existing data sets***. The preposition that current data should be considered to be the reference is not justified, even though it would preserve the internal consistency of the existing data. Merging the two data sources into an updated data set should be carried out while taking into consideration the accuracy of each data set, and upgrading of the existing data should be done whenever possible.

In view of these goals, an attempt is being made in this contribution to form guiding principles that will lay the foundations for updating procedures, which integrate the various steps required during the updating cycle while optimizing the amount of labor required. In the following chapters these guiding principles are detailed as follows: the second chapter describes a possible approach to minimizing the amount of up-to-date data; the third chapter outlines some guidelines for the change detection process; the forth chapter outlines possible techniques for the optimized incorporation of the new and the existing data sets. Concluding remarks are presented in the fifth chapter.

2 MINIMIZING THE UP-TO-DATE DATA EXTRACTION LABOR QUANTITY

The development of tools for automatic and reliable extraction of man-made features from aerial imagery will undoubtedly have extensive impact on the task of updating spatial data. Yet, although automatic feature extraction has been the subject of extensive research effort, various significant difficulties still exist (Sahar and Krupnik, 1997). In practical terms, these difficulties are manifested as the need for human intervention in the feature extraction process. Consequently, the ambition to reduce the amount of data extracted is eminent even if a semi-automatic feature extraction algorithm is implemented. This ambition is more prominent when features are extracted by a human operator. Hence, one of the primary (and straightforward) factors in minimizing the amount of labor involved in the extraction of up-to-date data is the reduction in the *quantity* of the data extracted.

A relatively simple way of achieving this goal is by implementing the local updating strategy, during which up-to-date data is extracted only in areas affected by change. It is self evident that this can be accomplished only when the location of the areas affected by change is known. Unless some a priori knowledge is available, such information is obtained only as a result of a change detection process, which requires either a complete remapping of the area of interest in the case of a semi-automatic process, or manual change detection in the case of a superimposition process. In both cases, no significant reduction in the amount of labor is attained.

A possible solution may be suggested by a different strategy, where the reduction in the quantity of the data extracted does not originate from reducing the area from which features are extracted but rather from a reduction in the *level of detail* of the data extracted. This “data generalization” facilitates a reduction in the amount of labor needed for initiating the change detection process without any prior knowledge regarding the location of areas affected by change. If a semi-automatic change detection procedure is to be performed, such a reduction in the level of detail can reduce the amount of data that should be processed, and again a reduction in time and complexity can be obtained. Following the detection of changes, only areas that were found to be affected by change should be remapped in full detail for the succeeding updating process, and a local updating strategy can be implemented. A drawback of this strategy originates from its inability to provide the change detection procedure with the full extent of detail of the data, therefore changes which are visible only in fine detail will not be detected. This, however, can be avoided if an appropriate threshold of the scope of change is set prior to the feature extraction process.

Considering this, such a strategy can be implemented sequentially. The process can be initiated by a low-detail photogrammetric mapping of the entire area to be updated using imagery, where the amount of information that can be extracted is limited either due to low image resolution or due to preprocessing. This information can be then processed for change detection using the existing data as reference. It must be noted that the existing data can not be directly compared to the up-to-date due to difference in the level of detail of the two data sets. Consequently, degradation of the existing data set is required. After such degradation is performed and changes are detected, a sequential process, with a more detailed remapping of the areas affected by change, can be initiated. This sequential processing step can be repeated several times, where in every step the level of detail of the data set used can be increased. Hence, a *pyramidal data structure* is employed for each data set during this process (Figure 1). This would provide the means to concentrate most of the remapping effort only on areas that were affected by change, resulting in minimizing the amount of labor involved in extracting the up-to-date data. The outcome of such a process would be “patches” of up-to-date vector data that are incorporated into the existing data set.

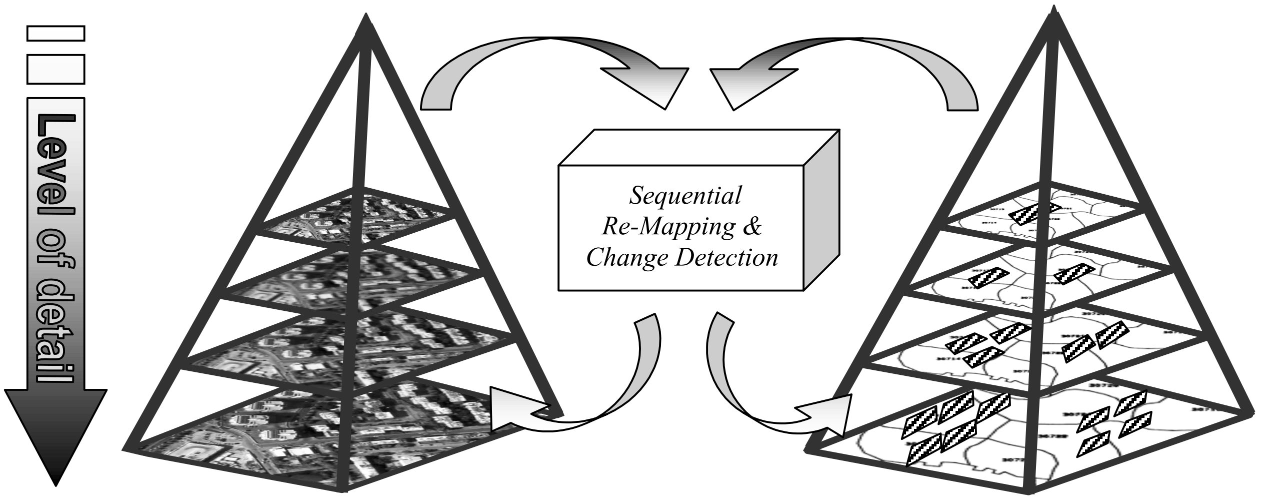

Figure 1. The sequential re-mapping and change-detection process

3 CHANGE DETECTION

The ability to detect differences between two or more spatial data sets is a core process in updating. It involves an attempt to establish correspondence between the existing and the up-to-date data sets, followed by analysis of corresponding objects. Consequently, four groups of objects can be constructed: (a) objects in the existing data set for which no correspondence was detected; (b) objects in the up-to-date data set for which no correspondence was detected (c) corresponding objects that underwent no change; (d) corresponding objects that underwent some degree of change (Ramirez, 1996). It should be noted that while classification of objects into groups (a) and (b) involves only establishing correspondence, classifying objects into groups (c) and (d) also involves comparing the *shape* of the corresponding objects.

A potential solution of the correspondence problem may be found in conflation, which involves a matching process between two vector data sets (Saalfeld, 1988). This can be realized by first matching junction points, followed by matching segments and nodes between matched junction points (Gabay and Doytsher 1994). Epsilon bands and a set of topological rules are used as matching criteria between segments and nodes in this process. The outcome of such a matching process is composed of a group of matched elements and a group of unmatched elements, which correspond to groups (a) and (b). Although this seems to provide an adequate solution to the correspondence problem, several drawbacks cast a shadow on its implementation. The extensive use of primitives (such as junctions, segments, and nodes) during the matching process is not only cumbersome, but is also ineffective for change detection in complex spatial objects (Gold, 1992). Furthermore, it requires that the two data sets share an identical datum.

The shape comparison task may be implemented by quantifying the concept of shape. Quantitative shape descriptors can be found for the internal as well as the external space domain of the shape, using a variety of mathematical tools (Pavalidis, 1978). The internal space domain description can be obtained by either decomposing the space into sub-spaces such as Primary Convex Subset decomposition (PCS), or by finding a set of axes that describe the shape, such as the Medial Axis. The external space domain can be described by Chain-Code or other syntactic description methods. In addition, tools for describing the shape of a set of points, such as Relative Neighborhood Graphs (NRG) or statistical parameters that describe disparity or average distance between points, have also been formulated (Taussiant, 1980).

Though the tools described can provide a solution to some degree, the key to a more comprehensive solution may reside in the best solution available today – the human operator. Most of the change detection work is performed today by human operators due to their ability to execute such tasks at high success rates. Consequently, an attempt to analyze how this is executed by the human brain appears to be a promising starting point toward an attempt to carry out this task automatically (Newby, 1996). Although the manner in which the human brain performs such tasks is still the subject of extensive research, several studies in the field of visual form show that the *shape*, as well as the *relations* between objects, are of great importance when performing such tasks (Saalfeld, 1997), (Loncaric, 1998). Thus, a successful detection of changes between sets of vector spatial data requires the ability to establish correspondence between objects, in addition to the ability to compare the shape of corresponding objects.

The implementation of this approach may be carried out in two steps. In the first step, the topological interrelations between objects in each data set are mapped. This is followed by an attempt to establish correspondence between the resulting interrelation maps. The comparison is to be based on the topological relationships, without an explicit comparison of the shape of the objects. The comparison of shapes of the corresponding objects will only take place in the second step.

4 INCOPORATION OF THE UP-TO-DATE AND THE EXISTING DATA SETS

Spatial data consistency involves ensuring compliance of the data with a set of predefined rules. This framework of rules is used for the verification of various attributes such as feasible topological relations or predefined values of metrics such as angle, length, and area (Kainz, 1997). Once established, the consistency of the data set must be reascertained after any data manipulation that might cause inconsistency. In the case of a local updating process, the up-to-date data patches contain both the data objects affected by change and the data objects that remained unchanged. When incorporated into the existing data set, data objects in the patch that remained unchanged will not necessarily precisely overlap their counterparts in the existing data set. This ambiguity is usually the result of factors such as the differences in datum, data quality, or the stochastic nature of the surveying process employed. Consequently, the consistency of an existing data set must be reexamined after a local updating process is performed, during which all ambiguities must be resolved.

The consistency and ambiguity questions can be avoided if the existing data set and the relations between data elements in it are used as constraints. In this case, the constraints can be expressed either in terms of point coordinate values or in terms of geometric relations and quantities, such as fixed length and angle value, co-linearity, or perpendicularity. Using these constraints, transformation parameters can be estimated between data objects in the patch that were unaffected by change and their conjugate objects in the existing data set. This can be done for the entire patch or for subsections in the patch (Rubber-Sheeting). It should be noted that due to practical considerations it is frequently preferable to use the techniques described even if errors are found in the existing data set (Walker, 1984).

The advantage of maintaining consistency and preventing ambiguities within the existing data set by imposing constraints is accompanied by the disadvantage of neglecting the stochastic nature of the existing data set itself. This data set is also the product of a measuring process, during which various errors may have been introduced and the accuracy of the data set was established. Taking into account only the geometric accuracy, three relations between the accuracy of the existing data set ($\sigma_{existing}$) and the accuracy of the up-to-date data set ($\sigma_{up-to-date}$) may take place:

(a) $\sigma_{existing} << \sigma_{up-to-date}$ - In this case it is fully justifiable to constrain the up-to-date data by the existing data since the accuracy of the existing data set is significantly better than the accuracy of the up-to-date data.

(b) $\sigma_{existing} \approx \sigma_{up-to-date}$ - In this case both data sets have similar accuracy, hence prioritizing one of the data sets is not justified. Although using the existing data set for constraining the up-to-date data set is not likely to degrade its accuracy, an opportunity to upgrade the existing data set is missed.

(c) $\sigma_{existing} >> \sigma_{up-to-date}$ - In this case it is not justified to constrain the up-to-date data set by using the existing data set. This results in distortions in the up-to-date data set, and an opportunity to upgrade the existing data set is lost.

As can be seen from the possible accuracy relations, neglecting such information may impair both the up-to-date and the existing data sets. Hence, the accuracy relations must be known prior to the incorporation of the two data sets. Once this information is available, proper weights can be assigned to each data source and an optimized data incorporation, which includes preventing distortions and taking advantage of upgrading opportunities, can be obtained.

When implementing this approach it may be assumed that $\sigma_{up-to-date}$ is obtainable. Since the up-to-date data is the product of a recent photogrammetric mapping process, information regarding the geometric accuracy of extracted features can be readily produced. This may not be the case in obtaining $\sigma_{existing}$. For some data sets this information is not available, while for others such information is available in the form of general estimates for the entire data set. Even when such estimates exist, they may not be suitable for use in a local updating process since $\sigma_{existing}$ may vary considerably within the data set. These considerations lead to the conclusion that an estimation mechanism for $\sigma_{existing}$ should be provided if an optimized incorporation of up-to-date data with existing data is sought. This mechanism should provide not only an overall estimate, but also a detailed estimate according to the patch that is to be updated. In order to facilitate such accuracy estimation, the up-to-date data, for which an accuracy estimate is available, may be utilized. By using unchanged conjugate objects from both data sets a possible solution may be formed by means of statistical analysis, from which either a relative or an absolute accuracy estimate may be derived.

5 CONCLUDING REMARKS AND FUTURE WORK

The concepts described are the basis of ongoing research toward formulation of an *optimized* updating solution for vector spatial data sets, where a framework of three processes is employed during its implementation. In the first process, an attempt is made to reduce the amount of labor required for extraction of up-to-date data, as elaborated in chapter 2. This requires proper degradation techniques for both the existing vector data set and for the up-to-date imagery, followed by a change detection process, as outlined in chapter 3. This process should be implemented by the widely used change detection technique based on human operators. While comparing the data sets in search of discrepancies, the topological relations between spatial objects, as well as the shape of the objects themselves are to be employed. A third process, which facilitates the incorporation of the up-to-date data into the existing data, concludes the updating scheme. As outlined in chapter 4, the attempt to maintain the consistency of the existing data set should not be the only guiding principle in this process. Instead, the integration of the two data sets should also be guided by the accuracy of each data set.

Within the framework described, considerable research effort was invested in recent years into the problem of automated feature extraction and change detection. Yet little attention was given to the problem of obtaining an optimized integration (“fusion”) of existing and up-to-date data, and to the realization of the upgrading principle during updating. To this was added the lack of an appropriate accuracy “probing” tool, which is a precondition for initiating such a solution in cases where detailed information regarding the accuracy of the existing data is not available. Motivated by these shortcomings, optimization of the updating process is being sought in this research in two separate contexts. In the first, optimization of the amount of resources invested in obtaining up-to-date data from aerial imagery is being sought. In the second, an optimized fusion of the existing and the up-to-date data sets is pursued. Should these goals be attained, the updating cycle may be shortened and the amount of resources invested in it may be reduced, hence updates could become more frequent. Additionally, the up-to-date data will not necessarily be constrained by the existing data and its quality will be retained, as an accuracy based data fusion process will be employed. This will also facilitate utilizing the up-to-date data to enhance the quality of the existing data whenever possible.

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