# A FRAMEWORK FOR ROAD CHANGE DETECTION AND MAP UPDATING

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**ABSTRACT:**

The updating of road network databases is crucial to many Geographic Information System (GIS) applications such as navigation, urban planning, etc. This paper presents a comprehensive framework for image-based road network updating, in which the following three tasks are performed sequentially: road extraction from imagery, road change detection and updating, and spatio-temporal modeling. For road extraction a multi-resolution analysis approach is used in combination with a novel road junction detection method. The road change detection and updating is one of the typical issues in the map conflation field. Feature matching techniques are applied to determine the changed and unchanged portions of the road network. A conflation step is then used to create an updated road network in which the attributes will be transferred from the existing database to the new database based on the conjugate features resulting from the feature matching step. For a pragmatic road updating system, a spatio-temporal modeler should be encompassed to efficiently and effectively store and make use of both the updated and old databases. The proposed methodology has been tested on updating the Canadian National Topographic DataBase (NTDB) based on road extraction from remotely-sensed imagery.

## 1. INTRODUCTION

Keeping the road network database up-to-date is important to many Geographic Information System (GIS) applications (e.g., traffic management, emergency handling, etc). In the geomatics community, there are several options to update a road network map, including ground surveying, vector map comparison, image-based updating, etc. Image-based updating is based on feature extraction from remotely-sensed imagery, which has become even more important recently because of the high spatial resolution (1-4 meters), fast orbit repeatability, rich multi-spectrum information and stable, affordable acquisition cost of satellite imagery [Hu & Tao, 2002].

Research on image-based geospatial change detection is rather limited, at least compared to the body of work on object extraction [Agouris et al., 2001]. Among the methods developed, we can mention particularly the work of Klang (1998). He developed a method for detecting changes between an existing road database and a satellite image. First, he used the road database to initialize an optimization process using a snake approach to correct road location. Then, he ran a line following process using a statistical approach to detect new roads, starting from the existing network. In Fortier et al. (2001), the authors extend the above approach by using road intersections. Road intersections improve matching between the road database and the lines on the image. Hypotheses for new road segments are generated from these line junctions. To avoid the pitfalls in GIS updates that result in storing multiple slightly different representations of an object that has actually remained unchanged, Agouris et al. (2001) extend the model of deformable contour models (snakes) to function in a differential mode. They introduce a new framework to differentiate change detection from the recording of numerous slightly different versions of objects that may remain unchanged.

Although the snake model has been successfully applied in feature extraction from imagery and change detection as well, the review of the previous work shows that a snake model-based approach to road change detection and updating has the following problems:

1) It requires the initial position of every snake which makes it of little use in finding new roads;

2) It is very sensitive to the initial position. An undesirable initial snake will lead to an inaccurate result;

3) In a typical road change detection scenario, there is an existing road database which provides an initial version of the snake. Very often, however, the end points of the existing road polyline will not be accurate enough to lead the road nodes to the desired positions after snake deformation;

4) It is also sensitive to the noise in the digital numbers along the road lines, which is often the case due to the complex radiometric background.

Usually a road updating processing will involve several issues, such as 1) the improvement of the weak positional accuracy of the existing road locations that remain unchanged; 2) the updating of the changed road; 3) the detection of the new roads; and 4) the transfer of attribute data from the previous version of the road database. These issues are among the typical concerns in map conflation research area. Map conflation is the process of creating a new database based on two or more different databases covering the same area [Cobb et al., 1998]. The new database is superior to any single one in the whole, with high accuracy, rich attribute information, up-to-date, etc.

This paper will present a framework for image-based road change detection and map updating.

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The paper is organized into seven parts. Firstly, a framework for an operational road database updating system is presented in Section 2. Road map updating modes are briefly discussed in Section 3 followed by a detailed description about road change detection and updating based on map conflation in Section 4. Section 5 addresses some key issues in modelling road network changes. Some preliminary results along this line will be illustrated in Section 6. Finally, some conclusions will be given in Section 7.

## 2. A FRAMEWORK FOR ROAD MAP UPDATING

Intuitively, an operational road map updating system should include the following three main functions:

1) Generating a new version of road features or the whole road network either by ground surveying or by road extraction from imagery;

2) Detecting road changes, i.e. identifying the roads that remain unchanged, have disappeared, or emerged recently;

3) Updating the road database. This includes updating the geometric data of the roads; transferring attributes from the old version to the new version database; and organizing both versions of the road databases in a spatio-temporal model.

A lot of work had been done in each of these three areas separately, but very few researchers have treated the three parts in a united way.

In this paper a wavelet-based road junction and centerline extraction processing is initially performed. Map conflation techniques are then applied for road change detection and updating. Finally, the change information of the road network is organized in an efficient way to facilitate spatio-temporal queries and spatio-temporal analysis. The proposed framework for an operational road database updating system is illustrated in Figure 1.

The wavelet-based road junction and centerline extraction has been detailed in the paper [Zhang & Couloigner, 2004] and will not be repeated here.

## 3. ROAD MAP UPDATING MODE

Both road change detection/updating and spatio-temporal GIS have been under research for more than ten years now. There are a lot of new ideas and new approaches promoted in both areas. However, most of the research is carried out separately and very few people are working on both problems simultaneously. The author would argue that a spatio-temporal perspective will be very helpful to develop an operational system for road change detection and map updating. On the other hand, a change detection and updating perspective will also shed some light on the research of temporal GIS.

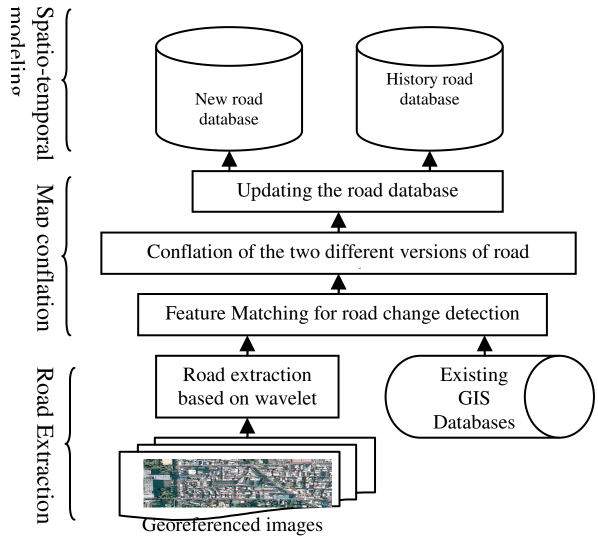


**Figure 1** The proposed framework for an operational road database updating system

Road maps could be updated by ground surveying, either by using a traditional method (total station, GPS) or by using a more automatic method (e.g., mobile mapping system). Usually, a survey team will be informed that some roads have been changed, go to the site and record the new positions of the roads. From a spatio-temporal point of view, this method is most suitable because only the changed roads should be taken into account and the time stamps could be easily put either at the tuple level or at the attribute level. In addition, the change is closely linked to the events which had caused the road to change. The minus of this method is that it needs many surveyors to focus on this task in order to record the change timely. Therefore, it is a costly and labour intensive way to update a road network database.

The second method is to use a more recent map to update the old road map. By feature matching, the unchanged and changed roads can be determined during the mapping time interval. This is an ad-hoc technology to maintain a road network database. The revision time may be one year or more than five years depending on the application purpose and other situations. It is obvious that this method is close to a snapshot approach to model the changes. Change has a very coarse temporal resolution. It may also be very difficult to determine when the road changes occurred because we have little information about the events which caused these changes. The transaction time/database time can be indicated at a table or tuple level because all the changes have the same transaction time. The valid time is difficult to determine unless all the changes have been recorded immediately after their occurrence.

The third method is to extract the road network and detect the changes based on new remotely-sensed imagery. This technology has been widely researched for many years. Although there are few successful fully automated techniques, there are many partially automated feature extraction techniques available to detect road network changes. The limitation is identical than for the second way: same transaction time for all the road changes and difficulties in identifying the valid time of the changes.

The methodology for road change detection and map updating based on map conflation technology is discussed in the next section.

# 4. ROAD CHANGE DETECTION AND MAP UPDATING BASED ON MAP CONFLATION TECHNOLOGY

Map conflation techniques are used in the change detection and updating stage in this research due to the following reasons.

1) Feature matching is a well-known map conflation technology to determine the conjugate features between two different versions of geographic databases. Both node feature matching and linear feature matching technologies could be used in road change detection processing;

2) Through feature matching we can not only identify the conjugate features so that the relative accuracy of the two versions of databases can be determined, but we can also determine which parts of the road network have changed and which parts remain unchanged. In addition, conflation operations can be performed to transfer attributes to the new database based on conjugate features;

3) Map conflation is also useful in the case where the improvement of the positional accuracy of the original version of the road database is necessary or desired. Both node-based conflation (e.g. TIN approach in [Saalfeld, 1993]) and polyline-based conflation (e.g. polyline mapping method in [Filin and Doysther, 1999; 2000]) could serve to correct the old version of the road database;

4) Map conflation is originally an editing operation in GIS to reconcile the position of related features. So the results from map conflation will have a good consistency between the changed and the unchanged road features.

After a successful extraction of road features from the imagery, feature matching is performed to identify the conjugate road nodes and road centerlines from the two versions of the road datasets. A conflation procedure then follows to obtain a new, more accurate road database. The main steps are detailed in the following subsections.

## 4.1 Node matching

Node matching, i.e., identifying the conjugate road nodes in the two versions of the road database, is usually the first step in map conflation.

Both distance and topological similarity measures should be used to find possible conjugate nodes. The calculation of distance similarity is usually based on the positional discrepancy between two points. The topological similarity is based on the "Spider code" of a road node which was originally presented by Saalfeld (1988, 1993). It is a measure of the structure information of a node based on the number of linked arcs and corresponding directions.

## 4.2 Point-based conflation

In this step, a point-based conflation is performed on the original road database in order to reduce the positional discrepancy between the two versions of the road database. The typical point-based conflation procedure is based on a piecewise local transformation determined by two TINs constructed from the conjugate nodes (see Cobb et al [1998] for a detailed description).

## 4.3 Polyline matching

Polyline matching is mainly used to identify the conjugate road lines, but at the same time, it could also be used to detect road changes.

Although both distance and shape similarity measures could be used for polyline matching, none of these measures is well defined for polylines.

There are some definitions for distance between two polylines, such as Hausdorff distance [Hangouet, 1995], $L_2$ distance [Saafeld, 1993], etc. Walter and Fritsh (1999) used buffering to assess the distance similarity between two lines in road feature matching. However, all these distance measures failed to give a meaningful similarity index for partially-matched line pairs. A modified intermediate area approach is used in this research which could solve the multiple matching issues. An appropriate shape similarity measure for road polylines may also be helpful in feature matching, however, it is still under development.

Based on the results from polyline matching, a road will be categorized into one of the following cases:

1) *Unchanged*, if the road arcs are successful in finding conjugate features;

2) *Disappeared*, if the road arcs in the original version of database failed to find conjugate features;

3) *Created*, if the road arcs in the new version of database failed to find conjugate features;

4) *Changed*, if the road arcs are successful in finding conjugate features but the positional discrepancy is significant;

5) *Partially changed*, if the road arcs are partially successful in finding conjugate features.

All this information will be helpful in updating the road database and will be used in the next processing step.

## 4.4 Polyline-based conflation

Polyline-based geometric conflation could be used to improve the accuracy of the original GIS data. This step is optional if the correction of the positional data of road polylines is not desired. Filin and Doysther (1999; 2000) introduced the polyline mapping method to correct the old version of the road database based on matched polylines.

## 4.5 Attribute transferring

Transferring the attribute data from the old version database into the new one is an important function for a map updating system. This step is simple for unchanged road features because these features will have 1:1 matching in the polyline matching step. However, problems may occur for those that have been recognized as partially changed. This usually should be done with the aid of user interaction. An appropriate "transferring" operation has to be chosen for each attribute. For example, if two new road polylines were found to be matched to one road polyline in the old road map, the name of the old road could be "assigned" to the two new road features, while the "length" value should be "departed" to the two new ones.

### 4.6 Modeling the changes

Organize the newly-updated road database and historic database using a spatio-temporal model for road network. A reasonable spatio-temporal model for road network is still under development.

## 5. ROAD CHANGE REPRESENTATION IN GIS

It is still an open issue to model changes in GIS. Many problems should be addressed in a productive environment. Several considerations regarding the change representation of the road network are discussed in the following subsections which are not necessarily complete.

### 5.1 Decomposition of non-spatial attributes

In a pragmatic system, road features will have a number of non-spatial attributes. Some of these attributes (e.g. length, width) will change as the road's geometric or spatial attributes change while the others (e.g. name, pavement materials) will change independently of the spatial attributes. Therefore, we suggest that we distinguish these two types of non-spatial attributes in road spatio-temporal modeling to minimize the total storage and improve the access efficiency.

### 5.2 Choice of spatial data structure

If a spaghetti structure is used to store the spatial data of a road, i.e. a series of coordinates of points is used as in ESRI Shape file or Autodesk DXF file, many problems might occur in both spatial and temporal data processing. For example, difficulties to maintain topological consistency may occur. In addition, storing a copy of the whole series of coordinates will be needed even if only part of the polyline changes. So a topological spatial data structure is a better suggestion to store spatial data of the road networks.

### 5.3 State-based vs. change-based

In early approaches, representations of objects (states) were stored at different time instances. In this case change information was handled indirectly, as it was not stored but could be calculated using the stored data. More recently change-oriented approaches have been introduced, focusing mostly on qualitative attributes of geospatial entities [Peuquet and Wentz, 1995] and variations of these attributes [Hornsby and Egenhofer, 2000]. Along this line, Mountrakis, et al (2002) also proposed a differential change model in which the change information is treated as explicit information.

In fact, each option offers benefits and costs. A state-based spatio-temporal database can answer a state-based query efficiently, e.g., *how did the road network look in 1998?* However, it has difficulty in answering a change-based query, e.g., *how many roads changed their centerlines during 1990 to 1992? In which sub-region did the road network change to the greatest degree?* On the other hand, a change-based approach may have fewer problems in answering these kinds of questions. However, more processes are required to answer a state-based query.

In a typical vector GIS, there are some additional problems with a change-based approach. Firstly, difficulties will occur in calculating the differential value of non-spatial attributes, such as "name", "class" and "pavement". Secondly, although the change representation proposed in [Mountrakis, et al, 2002] is simple and straight forward for a raster-based GIS or a polygon theme, it is not sufficient for a polyline change representation. Thirdly, to store the difference between two lines usually requires the same storage as to store a copy of one of the original lines.

We would argue that the choice of a state-based approach or a change-based approach is really an application-dependent problem. In the current prototype system, a state-based approach is used to organize all the non-spatial attributes and a change-based method to model the spatial changes of the road network.

### 5.4 Entity ID issues

In a GIS, each geographic entity is assigned a unique identifier (ID) to distinguish it from all other geographic entities. The assignment of an ID has a great effect on the spatio-temporal database design and implementation. Unfortunately, there is no unique way to make a decision on when to assign a new ID or when it has to remain the same. It is an application oriented issue. The method of assigning an ID in a cadastral information system is definitely different from the method in a road management system

Generally speaking, there are three kinds of spatial objects of concern in a road management system. They are polylines, nodes, and vertexes. A polyline is a representation of a real world road. Each polyline will have an ID to relate uniquely with the real world road. Any information about the road will be related to the same ID if all the changes are within the condition to maintain the same object ID according to the specific application. On the contrary, the vertexes have no extra information besides the positional information and a new vertex ID could be assigned whenever its position changes. However, this is not true in a cadastral information system, in which every point along the cadastral boundary (i.e. vertex) is important to the management units. To assign a new road node ID or not really depends on how many non-spatial attributes should be attached to the node entities and whether these attributes change along with the position change. For example, in a real world a road junction could be reconstructed and its position may be changed. But some other attributes of the road junction may still remain the same as before, such as the name or traffic signs. So we would suggest that we keep the same ID for the road node even if its position has been changed.

### 5.5 Summary of the spatio-temporal modeling for the road network

Based on the above discussions, the main features of the proposed spatio-temporal data model for the road network could be summarized as follows:

1) While the change information of a road line or/and a road node is recorded in the model, the change information of a vertex is disregarded. In other words, any change of an in-

ner vertex, that should be geometric change alone, will be treated as a creation of a new inner vertex;

2) The time stamp will be tagged at the feature level so that all the possible types of spatio-temporal changes to a road network can be tracked;

3) Although the current prototype model is generally a state-based approach, event information can be stored. It is from the event information that most of the change information of a road network, such as the change rate, change type or the most frequent change type, can be derived. This will satisfy many change-based enquiries;

4) The basic topological relationship is preserved in the model. This will maintain consistency in geometry while requiring a minimized storage volume;

5) Both spatial and temporal indexing approaches can be easily employed in this model.

## 6. APPLICATIONS

The whole project is still on-going. However, we have established a prototype system for image-based road change detection and map updating based on the proposed framework. The prototype system is built on Visual C ++ and ESRI MapObjects. The latter is mainly used for image and map viewing purpose. Figure 2 illustrates the main interface of the system.

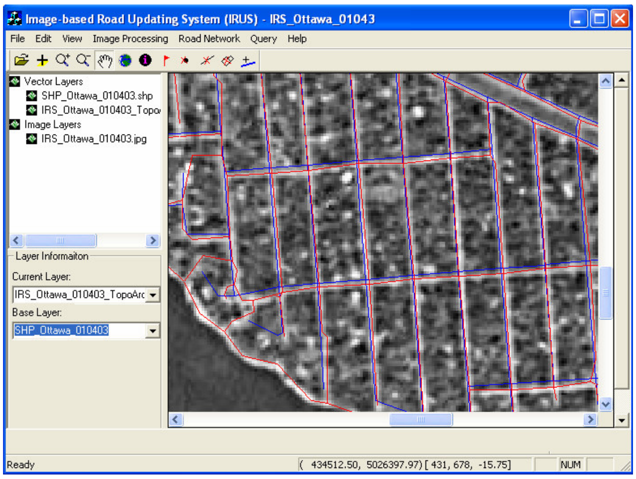


**Figure 2.** Prototype system for image-based road updating

The system consists of five parts, 1) map view; 2) image processing; 3) feature extraction; 4) change detection and updating; 5) spatio-temporal queries. A special data structure is used for road network spatio-temporal modeling, in which both the historic and the current information of the road network are incorporated.

## 7. CONCLUSIONS

Road change detection and database updating based on remotely-sensed imagery has been the objectives of many projects in the geomatics field. Due to its complexity, it is still a challenging topic. Three main functions, namely road extraction, change detection, and change representation, have to be included in an operational road database updating system. In this paper, a methodology for road change detection and updating based on map conflation technology has been proposed. A spatio-temporal model for road change representation has been also discussed.

Future work includes the full-implementation of an image-based road map updating system and the application of the system to production environments.

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