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A Spatio-temporal Data Model for Road Network in Data Center Based on Incremental Updating in Vehicle Navigation System

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Abstract: The technique of incremental updating, which can better guarantee the real-time situation of navigational map, is the developing orientation of navigational road network updating. The data center of vehicle navigation system is in charge of storing incremental data, and the spatio-temporal data model for storing incremental data does affect the efficiency of the response of the data center to the requirements of incremental data from the vehicle terminal. According to the analysis on the shortcomings of several typical spatio-temporal data models used in the data center and based on the base map with overlay model, the reverse map with overlay model (RMOM) was put forward for the data center to make rapid response to incremental data request. RMOM supports the data center to store not only the current complete road network data, but also the overlays of incremental data from the time when each road network changed to the current moment. Moreover, the storage mechanism and index structure of the incremental data were designed, and the implementation algorithm of RMOM was developed. Taking navigational road network in Guangzhou City as an example, the simulation test was conducted to validate the efficiency of RMOM. Results show that the navigation database in the data center can response to the requirements of incremental data by only one query with RMOM, and costs less time. Compared with the base map with overlay model, the data center does not need to temporarily overlay incremental data with RMOM, so time-consuming of response is significantly reduced. RMOM greatly improves the efficiency of response and provides strong support for the real-time situation of navigational road network.
Keywords: spatio-temporal data model; reverse map with overlay model; road network; incremental updating; vehicle navigation system; data center; vehicle terminal

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1 Introduction

Vehicle navigation system is an effective way of easing traffic pressure (French, 1997; Burnett, 2000), and the reliability and application of navigation function can be directly affected by the real-time situation of road network (Egenhofer, 1993; Zhang and Couloigner, 2004). The way of road network updating can be divided into whole version updating and local incremental updating (Cooper and Peled, 2001; Li *et al.*, 2009). The whole version updating, with a longer update cycle, is commonly used in the stand-alone mode of vehicle navigation system. With the development of wireless network, the vehicle navigation system, composed of data center and vehicle terminal, can transmit data using wireless network, which promotes the production of incremental updating technique for navigational road network. Incremental updating technique is flexible and can better guarantee the real-time situation of navigational data (Langran, 1993; Lin and Lee, 2004; Lin *et al.*, 2009), which is the developing orientation of navigational road network updating.

The vehicle terminal only stores the latest complete road network data, while the data center has to store not only the latest complete road network data but also the incremental data to meet the requirements of center

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navigation and autonomous navigation. In vehicle navigation system based on incremental updating, a large number of vehicle terminals send the data center incremental data requests and the query time when the vehicle terminals last update its road network. And the data center must transmit all of the road incremental data from the query time to the current moment to the vehicle terminals. Because the time when the vehicle terminals latest update road network is not necessarily the same, it is a challenging task for the data center to make quick response to incremental requests from lots of vehicle terminals. Therefore, a reasonable spatio-temporal data model which can effectively organize road incremental data to achieve a quick response is needed for the navigation database of the data center.

Although traditional road network models lacked the management of temporal data (Burrough and Frank, 1995; Goodchild, 2000; Li *et al*., 2004), several typical spatio-temporal data models that support road network storage have been proposed in the researches of geographic information system (GIS) (Goodchild, 1992; Egenhofer and Golledge, 1998; Erwig *et al.*, 1999; Peuquet, 2001; Wang and Cheng, 2001). However, the degrees of supporting incremental data storage are different for those models. In accordance with the applications of the models to storing navigational road network data and incremental data, they can be described as follows. 1) Time-slice snapshots model (Wood and Fels, 1986; Armstrong, 1988) that only stores complete road network data at the time when each road network change is easy to operate but produces data redundancy. That model does not store incremental data directly and incremental data need to be produced by spatial subtraction of complete road network data of different times, so the change process and variation are not obvious, which is not suitable for incremental data storage in the data center. 2) Base map with overlay model (Langran and Chrisman, 1988) was put forward for overcoming data redundancy, with which the data center only needs to store the earliest complete road network data and road incremental data at the moment of each road network change, but it reduces the efficiency of the response to incremental data required because of provisional data overlay. 3) Space-time composite model (Chrisman, 1984; Langran, 1992) can produce new entities as road network changing. Using that model, the incremental data have to be generated by spatial data operations of independent entities. Moreover, it has similar defects with the base map with overlay model when the data center makes response to the request of incremental data. 4) Space-time cube model was firstly put forward in the 1970s (Hägerstrand, 1974; Rucker, 1984). Although that model visually used geometric characteristics of the time dimension, it is too difficult to express three-dimensional cube model (Kraak, 2003; Wang, 2006), and the incremental data are not stored directly. 5) Spatio-temporal data model has been developed and studied (Herring, 1992; Raper and Livingstone, 1995; Usery, 1996; Gong, 1997; Cheng and Molenaar, 1998; Cao and Liu, 2002; Frihida *et al*., 2002) since object-oriented database technology was put forward (Khoshafian, 1990; WorBoys, 1992; Bagui, 2003). Peuquet and Duan (1995) gave an event-based spatio-temporal data model (ESTDM) on the basis of the object-oriented idea, and several other researchers including Chen and Jiang (2000), Lin *et al*. (2002) and Zhou *et al*., (2004) discussed the application of ESTDM. The data center stores the first complete road network data and events that are incremental data at the time of each road network change with ESTDM, so the issue that incremental data overlay affects the speed of response still exits.

According to the requirement of real-time situation of vehicle terminals, the spatio-temporal data model of the data center has to rapidly satisfy incremental data requests from large number of vehicle terminals. In this paper, a new spatio-temporal data model named reverse map with overlay model (RMOM) was developed based on the base map with overlay model, which is suitable for the data center to update road increment. The data center can quickly transmit effective incremental data to the vehicle terminal with RMOM when receiving incremental requirement. This model aims to improve efficiency of response of the data center and provide the support for quick road network data updating.

2 Establishment of Reverse Map with Overlay Model

2.1 Base map with overlay model

Using data of road network at a certain moment as base map, the base map with overlay model can generate new complete road network data by overlaying the incremental data and the basic data. When there are few overall variations, the model has high efficiency of updating and querying. However, the road network has the characteristics of more local changes than overall changes, so it was conducive to incremental updating for navigational road network using the idea of that model. Base map with overlay model only stores the basic map and variation at appropriate time interval. As shown in Fig. 1, it needs to store the basic map DATA-T_0 and incremental data at the moments when each road network changes, which are DATA-T_{1-0}, DATA-T_{2-1}, DATA-T_{3-2} and DATA-T_{4-3}.

2.2 Reverse map with overlay model

In this paper, we improved the base map with overlay model and developed the reverse map with overlay model. In the improved model, the navigation database of the data center stores not only the complete road network data at the current moment but also the overlays of incremental data from the time when each road network changes to the current moment.

The principle of storing road incremental data with RMOM is shown in Fig. 1. The complete road network is first stored in navigation database at T_0. If the road network changes at the moment T_1 and the road variation is DATA-T_{1-0}, DATA-T_0 is updated to produce the new complete road network DATA-T_1 based on incremental data DATA-T_{1-0}. As a result, the amended road network DATA-T_1 and incremental data DATA-T_{1-0} are stored in the navigation database. Provided that the road network changes at T_2 with the road variation DATA-T_{2-1}, firstly, the amended complete road network DATA-T_2 is achieved during spatial operations of DATA-T_{2-1} and DATA-T_1, and then new incremental data DATA-T_{2-0} are obtained by overlying DATA-T_{1-0} and DATA-T_{2-1}. Finally, the navigation database stores DATA-T_2, DATA-T_{2-1} and DATA-T_{2-0}. Similarly, when road network changes at T_4, the complete road network DATA-T_4, the incremental data DATA-T_{4-3} at the moment T_4 and all the incremental overlay data from the moment T_0 to the moment T_4 that included DATA-T_{4-2}, DATA-T_{4-1} and DATA-T_{4-0} are stored in the navigation database of

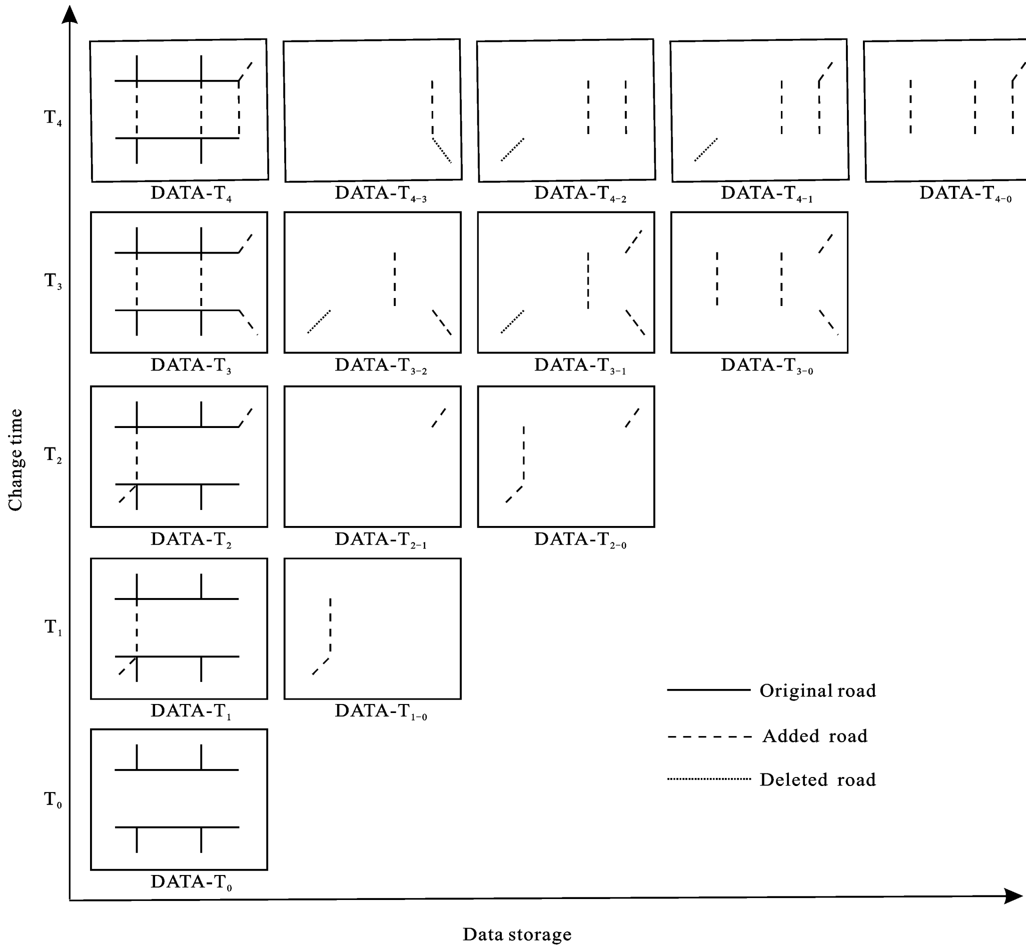

Fig. 1 Storage structure of road incremental data in navigation database of data center

the data center.

If the road network changes n times, the navigation database of the data center stores the complete road network DATA-T_n and all the incremental overlay data that were DATA-$T_{n-(n-1)}$, DATA-$T_{n-(n-2)}$, DATA-$T_{n-(n-3)}$, …, DATA-$T_{n-(n-i)}$, …, DATA-T_{n-1} and DATA-T_{n-0}, where $i > 0$ and $(n - i) \geq 0$.

After receiving incremental data request and query time from the vehicle terminal, the change times m of road network later than but nearest to the query time can be got by comparing the query time and the historical time of road network changed, and then the total change times n of road network can be obtained, so the needed incremental data DATA-$T_{n-(m-1)}$ can be searched in navigation database to meet the requirement of the vehicle terminal. As shown in Fig. 1, if the query time is between the first change and the second change of road network, the change number of the road network corresponding to the query time is two, and the total change number of the road network is four. In this case, the data center only needs to transmit DATA-T_{4-1} to the vehicle terminal to complete the response to the incremental request with RMOM. If the base map with overlay model is used, the data center has to overlay DATA-T_{2-1}, DATA-T_{3-2} and DATA-T_{4-3} firstly, and then transmit the overlay map to the vehicle terminal. Compared with the base map with overlay model, RMOM spends less time to complete the response.

3 Implementation of Reverse Map with Overlay Model

3.1 Storage mechanism and index structure of incremental data

All of the incremental overlay data and the complete road network were organized by layer and stored in a navigation database of the data center. In order to directly test the efficiency of RMOM, without the help of database management systems, part of hard disk of the server was used as navigation database to store road data. The layer name characterized the road incremental overlay data from the moments of road network changed to the current moment. For example, the layer name DATA-T_{n-m} expressed that the road network changed n times, and the data were the incremental overlay data from the time (m+1) of road network change to the current moment.

In order to facilitate the data center to query incremental data in the navigation database based on the query time, index file was built to store moments of road network changed, which was also convenient for naming the incremental overlay data.

The principles of designing the index structure were concision and rich semantic. Two fields in the index file were sequences of road network changed and the time of changes. Each row recorded one change of road network corresponding with the sequence of changes, and the format of the record was like ′k: year.month.day.hour′, such as ′3: 2009040410′ that described the third change of road network at 10 o'clock on April 4, 2009.

3.2 Program design of storing incremental data with RMOM

The processes of storing incremental data in the data center with RMOM were as follows. First, the data center received incremental data that would be named and stored in the navigation database based on the index file. Second, the time of change was recorded in the index file. Third, the data center needed to determine whether it was the first change of road network. If not, new incremental overlay data were named and stored, which were produced by spatial operations of the incremental data obtained and those incremental data added to the navigation database at the last change of road network. Finally, incremental updating was implemented in the complete road network in the data center. The program flow diagram of implementing RMOM can be seen in Fig. 2.

4 Efficiency Test of Reverse Map with Overlay Model

4.1 Test environment and data

IBM tower server, with 8 cores and 2 GHz of main frequency, was used to simulate the data center in vehicle navigation system and its operating system was Windows2003 Server. Desktop computers were used as vehicle terminals. The data center and the vehicle terminals were connected and the information was transmitted between them by wireless network. As one of ArcGIS′s components, ArcEngine was used to program for RMOM under the environment of Visual Studio2005.

The road network for test was a navigation electronic map of Guangzhou City, Guangdong Province, China in 2008 and the data format was Shape, which included

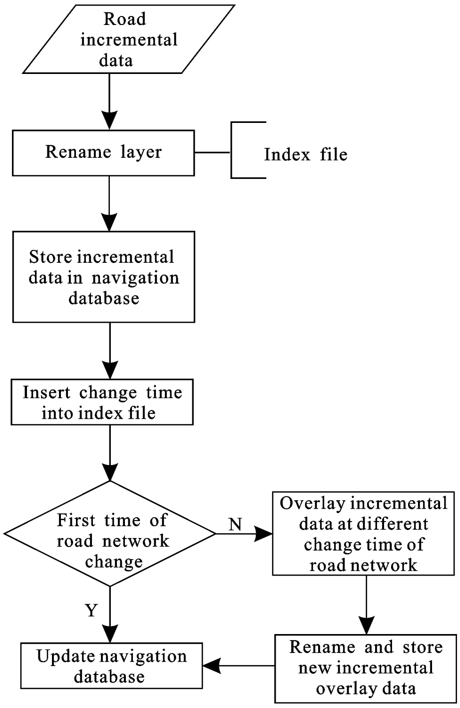

Fig. 2 Program flow diagram of implementing RMOM

73 521 road sections and 56 213 nodes. In the test, we set 30 changes of road network from the first time of producing incremental data to the current moment, of which the first 10 times changed one road section, the second 10 times changed ten road sections and the third 10 times changed one hundred road sections.

4.2 Response of data center to incremental data requirement from vehicle terminals

In reality, the road network of the vehicle terminals may be the complete road network at different times. In other words, the latest time of road network updating is different. For example, some vehicle terminals request incremental data immediately after receiving notification of road network change, while some others may request incremental data after several times of road network changes, so the query times from the vehicle terminals are different. In order to more comprehensively compare the efficiency of the traditional model and RMOM, the query times included any time of each adjacent change of road network, the time before the first road network changed and the time after the latest road network changed, so there was a total of 31 times of incremental data querying. Time-consuming of response was measured, which was the interval from receiving incremental data requirement to sending the needed data. Generally speaking, time-consuming of response was equal to the time of preparing and transmitting incremental data. Seeing that it took the traditional model and RMOM the same time to transmit incremental data, time-consuming of response only referred to the time of preparing incremental data in the data center in this paper. Because the change of road network was carried out in accordance with time sequence, when receiving incremental data requirement, the data center judged whether the query time was earlier than the moment of the first road network change or later than the moment of the latest road network change. The former meant that the needed data were the incremental overlay data at all moments of road network change. The latter meant that the road network of the vehicle terminal was the latest that did not need to update. The binary search algorithm was used throughout the query process.

4.3 Test results

With RMOM, time-consuming of the data center responding to the incremental data requirement is the time of only querying the needed data. However, it includes the time of querying and overlaying incremental data that are all incremental data from the query time to the current moment using the base map with overlay model. Using these two models, the data center responds to the requests of incremental data for 31 times, and the time-consuming is compared in Fig. 3, where t_i corresponds to the time-consuming of responding when the query time is any moment between the time $(i-1)$ and the time i of road change. And t_1 corresponds to the query time that is before the first road network change and t_{31} means the time after the latest road network change.

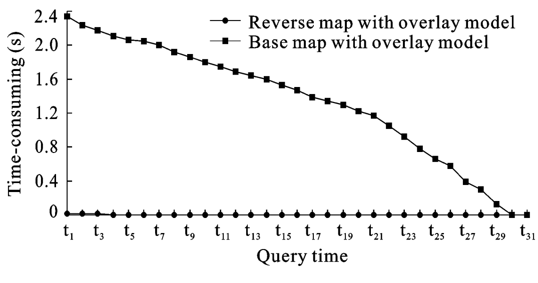

Fig. 3 Time-consuming of responding to incremental data requirement in data center

From Fig. 3, we can obtain the following results:

1) Using the reverse map with overlay model, the time-consuming of the response of the data center to

incremental data requirement from vehicle terminals is less and there are little difference of the time-consuming among different query times. The data center only needs query operation to respond to incremental data requirement, so it costs less time. And the data center spends approximately the same time for each search using binary search principle under the condition that only 30 times of road network changes exit in the test.

2) Using base map with overlay model, it needs more time for the data center to response to the request from vehicle terminals, and there are large difference of the time-consuming among different query times. That is due to that the time-consuming of the response includes the time of querying and overlaying incremental data, while the latter takes more proportion and depends on the amount of incremental data layers and the total amount of incremental data. For example, at the query time corresponding to t_1, the data center needs to overlay 30 incremental data layers which include ten layers with one road, ten layers with ten roads and ten layers with one hundred roads, while at t_{29}, it only needs to overlay two incremental data layers, each of which includes one hundred roads. As a result, the time-conuming are quite different at the two moments.

3) Compared with base map with overlay model, using RMOM, the data center does not need to temporarily integrate the incremental data and the time-consuming of response is significantly reduced. The more changes of road network happen between the query time and the latest time of road network updating, the greater the gap of time-consuming of response will be with the two models. For example, at the query time t_1, the time-consuming of response is more than 2.3 seconds with base map with overlay model while it is less than 0.02 seconds with RMOM. The data center only needs to query without the need of overlaying at the query time t_{30} or t_{31}, so time-consuming is the same with the two models.

5 Discussion

No matter the data center uses reverse map with overlay model or other spatio-temporal data models, time-consuming of transmitting incremental data by wireless network is nearly the same, so the speed of response is determined by the time efficiency of preparing the required data. When time-slice snapshots model, base map with overlay model, space-time composite model, space-time cube model or ESTDM is used, the needed data are obtained by spatial operations in the navigation database and the time-consuming depends on the amount of incremental data and the moment of the road network in the vehicle terminal. In contrast, using reverse map with overlay model, the data center does not need to temporarily overlay the incremental data, which improves the efficiency of response.

Reverse map with overlay model also contributes to the generating complete road network of different times. As the navigation database only stores the road network at current moment, more than one incremental data files are needed to produce new complete road network using base map with overlay model or other similar models, while one file is enough when reverse map with overlay model is used and this improves the efficiency. Similarly, this model also has advantage in the incremental information querying of a certain moment.

The high efficiency of reverse map with overlay model is achieved at the price of increasing the time of road network incremental updating in the navigation database, which firstly updates the road network when changes occur. Compared with base map with overlay model, it costs more time on the integration of incremental data of different times, so incremental updating of navigation database needs a longer time.

Suitable data model of the data center can not only meet the high response efficiency but also save data storage. Although both the base map with overlay model and reverse map with overlay model store equal incremental data files, the amount of each file is indeed different. Data of the former are the incremental data of adjacent changes of road network, while the latter are the integration of the incremental data of different moments. If the road network always adds or deletes road sections, data storage is greater when reverse map with overlay model is used. However, there are less data to store when both road sections addition and destruction happen using this model. Moreover, with the improvement of computer storage technology, data storage capacity is not the main factor restricting the spatio-temporal data model.

6 Conclusions

Using the reverse map with overlay model, a spatio-temporal data model was designed in this paper. When there is a change in road network, the data center will firstly obtain incremental information and then complete the storage of the incremental data as well as incremental overlay data, waiting for request of incremental data from the vehicle terminal. Although there are many possibilities of the query moment of requesting, which may be the moment before several road network changes or between the latest two incremental updating of the navigation database, the data center searches only once to obtain the required data when accepting the incremental data requirement, and the time-consuming of the response to the incremental data requirement from the vehicle terminal is equal to the time needed by querying historical incremental data.

According to the base map with overlay model, the needed incremental data are overlaid firstly, so the time-consuming of response in the data center includes query time and incremental integration time, and the time of integration is proportional to the times of road network changes from the query time to the current moment. The more times the road network changes during that period, the longer the response time of the data center is, and the lower efficiency is achieved with base map with overlay model.

RMOM does not reduce the time of the whole process needed from receiving incremental data to the completing incremental data updating, on the contrary, it increases the time of overlaying. However, it spends most of time before the vehicle terminal sending requests, which improves the response speed. Besides, the efficiency of response in the data center is improved especially in the situation that many changes of road network happen from the query time to the current moment.

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