Development of Advanced Vehicle Tracking System Using the Uncertainty Processing of Past and Future Locations

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Abstract: The e-Logistics means the virtual business activity and service architecture among the logistics companies based on the Internet technology. The management of vehicles' location in most conventional vehicle tracking system has some critical defects when it deals with data which are continuously changed. It means the conventional vehicle tracking system based on the conventional database is unable eventually to cope with the environment that should manage the frequently changed location of vehicles. The important things in the evaluation of the vehicle tracking system is to determine the threshold of cost of database update period and communication period between vehicles and the system. In other words, the difference between the real location of vehicle and the data in database can evaluate the overall performance of vehicle tracking systems. Most of the previous works considers only the information that is valid at the current time, and is hard to manage efficiently the past and future information. To overcome this problem, the efforts on moving objects management system(MOMS) and uncertainty processing have been started from a few years ago. In this paper, we propose an uncertainty processing model and system implementation of moving object that tracks the location of the vehicles. We adopted both linear-interpolation method and trigonometric function to chase up the location of vehicles for the past time as well as future time, respectively. We also explain the comprehensive examples of MOMS and uncertainty processing in parcel application that is one of major application of e-Logistics domain.

1. INTRODUCTION

The logistics concepts can be defined as the set of processes to satisfy the customer's requirement from the production to ultimate consume which consist of planning, execution, and control for the efficient and minimizing the cost of information flow of raw material, semi-processed goods, and finished goods. The logistics environment has been unlimitedly changed, and should be effectively correspond to the requirement of more flexibility and efficiency. Therefore, new logistics technologies, namely e-Logistics, are urgently needed because the conventional logistics technologies are hard to support the revolutionary e-Business.

The definition of e-Logistics is the virtual logistics business activity and service architecture among the companies based on the Internet technology[4]. Also the e-Logistics framework which is expansion of conventional logistics framework enables the business integration among the separated information system. It supports various kinds of functions such as real-time monitoring for the logistics information flow, intelligent controlling for the unexpected logistics state, and logistic optimization for the dynamic and intelligent readjustment of logistics planning. The moving objects techniques are one of major components of e-Logistics intelligent systems which work on based on the e-Logistics integrated platform.

In this paper, we propose the model and system design of moving objects uncertain processing system. In Chapter 2, we introduce the concepts of e-Logistics and moving object uncertainty technique as background and motivation of this work. The moving object uncertainty processing model in e-Logistics is shown and the detailed explanations of sub-systems are described in Chapter 3. In Chapter 4 and 5 are devote to the examples of moving object uncertainty core algorithm and application in e-Logistics and the summing up the previous related works, respectively. The conclusion and future research works of moving object uncertainty are summarized in Chapter 6.

2. BACKGROUND AND MOTIVATION

The database technology in most conventional vehicle tracking system has some defects when it deals with data which are continuously changed. The management of vehicles' location is one of the most representative problems. Because the exact data in the conventional databases are determined only by the update operation, the vehicle tracking system produces always invalid answer. It means the conventional vehicle tracking system based on the conventional database is unable eventually to cope with the environment that should manage the frequently changed location of vehicles.

The important things in the evaluation of the vehicle tracking system is to determine the threshold of cost of database update period and communication period between vehicles and the system. In other words, the difference between the real location of vehicle and the data in database can evaluate the overall performance of vehicle tracking systems. Although there are some

Table 1. Moving Object Databases Schema

(a) VehicleInfo_T

VehicleID	Type	DriverName	CellularPhone	Depot	Etc
VarChar2(10)	VarChar2(10)	VarChar2(8)	VarChar2(13)	VarChar2(32)	VarChar2(64)

(b) VehicleOperation_T

VehicleID	XS	YS	XE	YE	Velocity	Direction	VF	VT	Etc
VarChar2(10)	Number(18,9)	Number(18,9)	Number(18,9)	Number(18,9)	VarChar2(3)	VarChar2(3)	VarChar2(12)	VarChar2(12)	VarChar2(16)

methodologies to reduce the difference, there are also limitations to resolve the operational problems in the real world. The searching operation with complex conditions used in the various businesses requires too much cost in terms of computing time and is hard to keep step with the deadline defined in the given business.

Moving objects are spatiotemporal data, which change their location or shape continuously over time. Generally, if these continuously moving objects are managed by a conventional database, it is difficult to store all the location information changed over time in the database. Therefore, a time period of regular rate is determined and the location information of moving objects are discretely stored in the system for every time period. However, if the continuously moving objects are managed as discrete model, we may have problems which cannot properly answer to the query about the uncertain past and future location information. This problem is caused by the uncertain location information of the moving objects. Then a new model is required to answer properly to the location queries and to reduce the location uncertainty of the moving objects resulting from storing and managing continuously moving data in discrete model.

Successful e-Logistics operation depends on the effective support of the visibility in the intelligent system. Also the moving objects technology is one of the most valuable areas to be researched as well as developed. With these reasons explained above, the research and development of moving objects in e-Logistics are very important. From the next chapter, we show the architecture of Moving Object Management System(MOMS) and describe the detailed function of sub-systems which are composed of it.

3. MOVING OBJECT AND UNCERTAINTY PROCESSING

3.1. Moving Object Model

A field of ongoing research in the area of spatial databases and Geographic Information Systems (GIS) involves the accurate modeling of real geographical applications, i.e., applications that involve objects whose position, shape and size change over time [1]. The moving object can be defined as a special kind of spatio-temporal data which the location and shape changes continuously over time. There are two kinds of moving objects such as the moving point related to the change of location and moving region related to the change of shape. In this paper, we are dealing only the moving point because the vehicles in postal logistics can be classified to the moving point [3].

[Definition 1] (Moving Point Object : MP) It stands for the special type of spatio-temporal data that changes its location over time flows. It consists of the temporal attributes(T_A), spatial attributes(S_A) and the general attributes(G_A). The conceptual structure can be described as $MP = < T_A, S_A, G_A >$.

□

[Definition 2] (Temporal Attributes) It is one of elements of the moving point object(MP), and is composed of the both beginning(VT_s) and ending(VT_e) of the valid time when the object were valid at the location. Its conceptual structure is $T_A = < VT_s, VT_e >$. The VT_s and VT_e is an element of valid time domain(D_{VT}). Here the D_{VT} means the set of timestamps that is used in the real world and represented as $D_{VT} = \{t_0, t_1, t_2, ..., t_k, ..., t_{now}\}$. Each of elements in D_{VT}, there are some special characteristics as follows: $t_0 < t_1 < t_2 < ... < t_k < ... < t_{now}$, $t_k = t_{k-1} + 1$, $t_k = t_0 + k$.

□

[Definition 3] (Spatial Attributes) It is also one of components of moving point object. Its conceptual structure is described as $S_A = < x, y >$. x and y is a coordinate value.

□

The Moving objects database based on the spatio-temporal databases technique is composed of two major tables to store sampled location data of moving objects. The detailed scheme structure for each of them has been shown in Table 1.

In VehicleInfo_T table, the VehicelID and DriverName is the key value as an identifier of the moving object. The Type, CellularPhone, Depot, Etc are for the properties of each object including non-spatial information. Movement information table, i.e. VehicleOperation_T, stores historical information regarding sampled time and location of the object. In VehicleOperation_T table, the set of VehicleID, VF(Valid From), and VT(Valid To) is the key value. And the XS, YS, XE, YE specifies sampled time

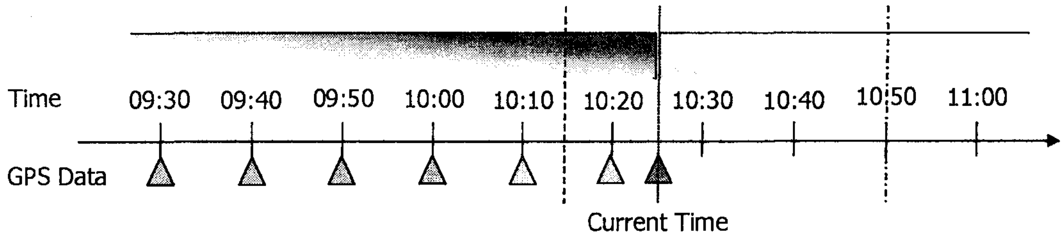


Fig. 1. Moving Object Uncertainty Query Types: Retro- vs. Pro-active

point and location coordinate values. Finally, the Velocity and Direction attributes are the additional information calculated directly from the location detecting devices.

3.2. Uncertainty Processing

3.2.1 Model

The definition of moving object is special kinds of spatiotemporal data which the location and shape of spatial objects continuously change with time. There are two kinds of moving objects such as the moving point related to the change of location and moving region related to the change of shape. In this paper, we are dealing only the moving point because the items in e-Logistics are not the moving region but also moving point.

To manage the moving object, we adopted the relational semantic model with spatial and temporal components. We also defined 10 kinds of operators for the moving objects and the *NearestTrajectory* is one of core operator in the moving object management system.

There are generally 4 sorts of reasons that give rise to happen uncertainty of moving object such as (a) the inadequate period which gathers location data, (b) the errors in telecommunication and databases(physical layer), (c) the illegal road and traffic information(logical layer), (d) the unexpected events in applications.

In case of the first type of them is related to the cost for gathering the location data of moving objects. Also the overall performance can be determined directly by the size of packets among the units and databases in the center. The efficient strategy to estimate the locations that were not collected by the detecting devices is one of major issues in the uncertainty domain.

The uncertainty concepts are bringing into relief when users request the locations at some time for the moving objects. Usually the temporal management is always included into the moving object techniques. Intuitively, there are two kinds of query types in uncertainty processing which can be handed in the users to the system as shown in Figure 1. On the basis of current time, (a) the retro-active uncertainty queries request the locations that can be estimated among the past locations, on the other hand (b) the pro-active uncertainty queries demand the future location which means the location where should be calculated in terms of time, i.e. immediately after of current time. According to the application domain, there are no means to get the pro-active uncertainty locations because they are generally determined by the human so that no one can decide the exact location of moving objects, for examples, the exact location of vehicles after 1 hour in the metropolitan city.

3.2.2 Formal Semantics

There is a representative operator, i.e, AtTime, which is one of typical moving object operators and is related directly to the uncertainty processing. The AtTime(R_i,T_i) returns the location P_i at the given time T_i for the input trajectory R_i. (1) shows the formal semantics of AtTime(R_i,T_i) operator with relational calculus.

$$\text{AtTime}(R_i\ ,\ T_i) = \{P_x \mid \exists x, y \wedge (P_y, T_j) \in R_i \wedge P_x \equiv P_y\} \qquad (1)$$

As shown in (3), the AtTime operator searches the point included in the trajectory, and can be rewritten to support the uncertainty of location like below (2)~(5):

- Whenever the location requested be the users query is not found in the moving object databases, it should at first retrieve the locations which is just prior to the input time and immediately after of the time.
- And then special operation such as interpolation would be applied to the locations to estimate the point that means the location at given time.

$$AtTime\ (R_i, T_j, \text{Pr}) = \begin{cases} P_x \mid \exists y \wedge (P_y, T_j) \in R_i \wedge P_x \equiv P_y \\ P_x \mid P_x \equiv UcR_{\text{Pr}}(R_i, T_j) \end{cases} \qquad (2)$$

$$UcR_{\text{Pr}}(R_i, T_i) = \begin{cases} P_x \mid P_x \equiv LI(R_i, T_i) \wedge \exists k \wedge (P_k, T_j) \in R_i' \wedge P_k \propto UcB(P_k, \text{Pr}) \wedge P_x \equiv P_k \\ P_x \mid P_x \equiv LI(R_i, T_i), otherwise \end{cases} \qquad (3)$$

$$LI(R_i, T_j) = \{P_x \mid \exists m, n \wedge (P_m, T_{j-1}) \in R_i \wedge (P_n, T_{j+1}) \in R_i \wedge P_x \equiv \frac{P_n - P_m}{T_{j+1} - T_{j-1}}(T_j - T_{j-1}) + P_m\} \qquad (4)$$

$$UcB(P_x, \text{Pr}) = \{C_i \mid \exists m, n \wedge (P_m, T_{i-1}) \in R_i \wedge (P_n, T_{i+1}) \in R_i \wedge C_i \equiv \delta(P_m, P_n) * \text{Pr}/100\} \qquad (5)$$

As explained at the previous section, there are several kinds of method to estimate the location of uncertain time. (a) *Nearest value* method determine the nearest location from the two or three locations which were stored in the database and is nearest to the estimated location, (b) *Linear interpolation* method estimates the uncertain location where is one location exist in the line which stems from two locations with simple equation, (c) *Spline interpolation* method differs from the linear interpolation, and uses two locations and additional location with spline equation, (d) *Stochastic interpolation* method is a probabilistic scheme which is based on the quasi-random generator, dimension-split line, and several locations.

The uncertainty processing in e-Logistics estimates the location of vehicles between the depots and customers. These vehicles have their own routing and scheduling plan and equipped with location-detecting devices such as GPS(Global Positioning System).
Under the above environment, the uncertainty processing can gives users below functions:

- Estimated location of past time
  - It were not stored at moving object databases, and calculated with probabilistic weight from the locations which were stored.
- Expectation of future location which is immediately after the current time

3.2.3 Algorithms
The moving object uncertainty processing system adopts a linear interpolation method to determine the location which was estimated from the given two positions. The detailed processing algorithm is can be described as below :

```
Location getFutureLocation(VehicleID, ValidFrom)
{
    timeInterval  =  CurrentTime - ValidFrom;
    current_x     = Xcoord from MODB;
    current_y     = Ycoord from MODB;
    speed          =  Speed from MODB;
    angle         = Course from MODB;
    distance      = speed * timeInterval
    fx = current_x + ( distance * cos( 90- angle ));
    fy = current_y + ( distance * sin( 90 - angle ));
    return fx, fy;
}
```

(a) Trigonometric Function

```
Location Huncertain(VehicleID, Time, Interval) {
    rs = Tuples which include Time given from Query from Historical Table;
    while (rs is NOT null) {
        fx = Xcoord of VehicleID which valid at ValidFrom from rs;
        fy = Ycoord of VehicleID which valid at ValidFrom from rs;
        tx = Xcoord of VehicleID which valid at ValidTo from rs;
        ty = Ycoord of VehicleID which valid at ValidTo from rs;
        lx = {((tx - fx)/Interval)*(Time - cvf) + fx};
        ly = {((ty - fy)/Interval)*(Time - cvf) + fy};
    }
    return lx, ly;
}
```

(b) Interpolation Method
Fig. 2. Uncertainty processing algorithm

3.3 Implementation
The moving object uncertainty processing system adopt two kinds of uncertainty processing method such as Linear interpolation method and Trigonometric function(Default) explained in the previous section.
The detailed procedural steps of algorithm is described as below :

[Basic Processing Step]

- Get the query time(t) and probability(pr) from the user;
- Retrieve two locations(p1, p2) which are corresponding the timestamps(t1, t2) contains user's query type(t);
- Calculates the location(p) for the query time(t) using the linear interpolation method. Here the location(p) can be defined with the ratio of query time(t) from the locations(p1, p2);
- Computes the uncertainty boundary of p, based on the velocity value and input probability corresponding to p1.

[Additional Processing Step]

- If there is any historical data(p') of p corresponding to query time(t), p should be revised to p'. p' also should be exist within the uncertain boundary.

In order to set p to the real world value, there is also additional processing such as map matching process. As the guideline to select the uncertainty value, the road overlaps with the uncertainty boundary must be preferred, and the direction(North, East, South, West order) is also preferred in case two of more roads are overlapped with uncertainty boundary.

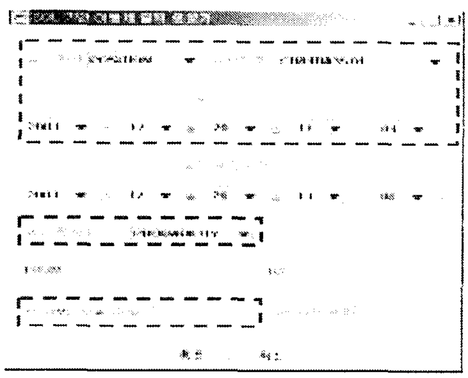
The default value in uncertainty processing can be defined as below: (a) the probability value is set one of 0%, 25%, 50%, 75%, 100% and used to determine the size of uncertainty boundary, (b) predefined default value of probability is set to 0%, it returns "No values" if input query time is not equal nor overlap, (c) When user set the probability value except 0%, the linear interpolation method is adopted to compute the uncertainty boundary. (d) the uncertainty boundary(UcR) is determined by the velocity of moving object stored in the databases and the probability input by the user.

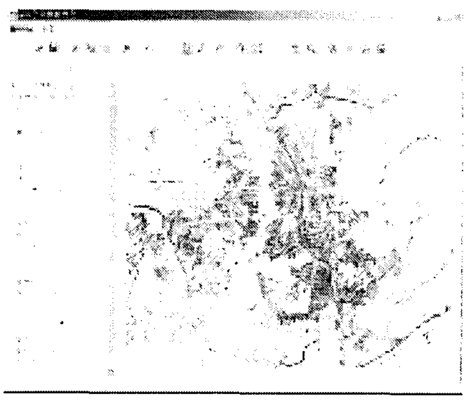
4. COMPREHENSIVE EXAMPLES

The vehicles equipped with GPS and CDMA communication devices deliver parcels to customer everyday. Their delivery route and schedule are determined by virtual optimization system or hand. The location data encoded by WGS-84 representation is sent to Logistics Center every 5 seconds. The location data are stored in spatiotemporal databases with the *validtime* stamps. Let's assume the default interval of storing location data is 2 minutes.
In the simple experiment where 2 vehicles are run from the shopping mall for 2 hours, the amount of the location data were decreased up to a half compare to the conventional method. As shown in Figure 3, user can trace the location of vehicle using the moving object uncertainty user interfaces with minimum probability of failure.
The MOQL[6] was defined based on the SQL with the spatiotemporal operations.

[Query 1] Retrieve location of vehicle(CB81Ba3578) which was valid at 2003-12-20 11:01 with probability 70%.

```
[MOQL] SELECT POSITION
       FROM VEHICLEHISTORY
       WHERE ID='CB81BA3578' AND
             VALID AT '200312201101' AND
             PROBABILITY 70 PERCENT;
```





[Query-2] Retrieve location of vehicle(CB81BA3578) at NOW within 4 minute with probability 50%.

```
[MOQL] SELECT POSITION
       FROM VEHICLEHISTORY
       WHERE ID='CB81BA3578' AND
             VALID AT NOW + 4 MIN AND
             PROBABILITY 70 PERCENT;
```

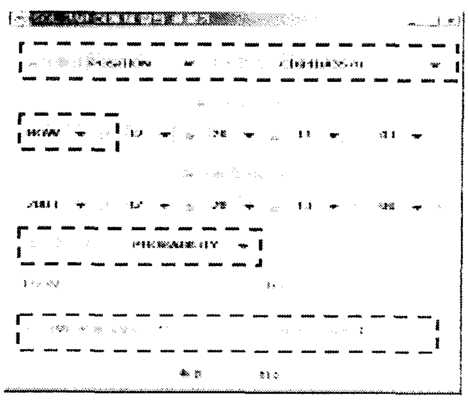


Fig. 3. Uncertainty Processing Snapshot

5. PREVIOUS AND RELATED WORKS

Pfoser[4] suggested the representation of the positions of moving objects in database, a method for acquiring and representing the movements of point objects with the uncertainty, and an application scenario based on the GPS. An integrated comprehensive framework of abstract data types for moving objects including base types, spatial types, time types, and spatiotemporal versions of them was presented in Guting's work[1]. In addition, Erwig[2] proposed an abstract and discrete modeling of spatiotemporal data types, which views moving points and regions as three-dimensional or higher-dimensional entities whose structure and behavior is captured by modeling them as abstract data types.

In modeling continuously changing moving objects, uncertainties have to be considered because of a measuring error and a sampling error. The measuring error can be produced even with very accurate measuring equipments. And the sampling error is changed by the frequency of acquiring the location samples. These uncertainties of the moving objects cause some problems such as database modeling, query processing, indexing, and incorrectness of results to the queries. Especially, the incorrectness of the answers to the queries may give wrong decision-making factors to the users.

To solve these problems, Pfoser[5] suggested the method for specifying the moving objects with a relational database and the method for measuring uncertainties with error information. In addition, in defining the location of the moving points of objects, the method to measure the non-sampled uncertain location using linear interpolation was proposed. However, it is a suggestion of the methodology, which lacks the accuracy verification through a concrete experiment. Also, Pfoser introduced a modeling method of uncertain changes using probability and the theory of fuzzy sets. Definition and the method of uncertain location estimation of moving objects using a database are not concrete. Sistla and Wolfson proposed a method to predict the future location of moving objects based on the current location of the object, speed, and direction. The current research of DOMINO refers to the location update policy, and uncertainty of the location related to database specifying. It also suggests ways to deal with queries of tracking current and future locations. To control the uncertainty and imprecision, it suggests the extension of the MOST model and query, the response about uncertain query using the probability and the compromise between update cost and the uncertainty cost of the database, and so on. However, neither does the MOST model store history information of the uncertain past movement location of moving objects, nor does it indicate the method to predict the past location.

6. CONCLUSIONS

The moving objects technology not only makes possible to overcome the problems in conventional vehicle management, but also gives additional information that are required to efficient decision making. The uncertainty of moving objects causes problems in database modeling, processing the queries, indexing, and inaccuracies of replying to the queries. The inaccuracy in answering the queries may cause wrong decisions by the user.

In this paper, we proposed the moving object uncertainty model and system architecture. We also show an example of moving objects uncertainty technology in e-Logistics. In our experiments, the degree of accuracy for tracking the locations of vehicles in e-Logistics has been enhanced up to 5~10%. It also decrease the volume of location data of vehicles up to 33~50%. In the future, we are to modify the algorithms to cope with the detailed road and traffic characteristics such as alleyway.

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