論文
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Estimation of Uncertain Moving Object Location Data

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요 약

이동체는 시간에 따라 위치나 모양이 연속적으로 변하는 시공간 데이터이다. 이동체의 위치 좌표는 정기적으로 측정되어 응용 시스템에 저장된다. 시스템에 저장되지 않은 질의 시점의 위치 정보를 추정하기 위해 선형 함수가 주로 이용되었다. 그러나 선형 함수에 의한 위치 추정은 추정 오차를 발생시키므로 위치 표현의 불확실성을 개선하기 위한 새로운 방법이 요구된다. 이 논문에서는 선형 함수에 의한 위치 추정 오차를 감소시키기 위해 3차 스플라인 보간법을 적용한 방법을 제시한다. 첫째, 2차원 공간에서 이동체의 위치 정보를 정의한다. 둘째, 제안한 데이터 모델의 위치 추정을 위해 3차 스플라인 보간법을 적용하고 알고리즘을 기술한다. 마지막으로, 제안한 추정 연산 모델의 정확성을 실험하였다. 실험 결과 선형 함수에 의한 방법보다 더 정확한 결과를 나타내었다.

Abstract

Moving objects are spatiotemporal data that change their location or shape continuously over time. Their location coordinates are periodically measured and stored in the application systems. The linear function is mainly used to estimate the location information that is not in the system at the query time point. However, a new method is needed to improve uncertainties of the location representation, because the location estimation by linear function induces the estimation error. This paper proposes an application method of the cubic spline interpolation in order to reduce deviation of the location estimation by linear function. First, we define location information of the moving object on the two-dimensional space. Next, we apply the cubic spline interpolation to location estimation of the proposed data model and describe algorithm of the estimation operation. Finally, the precision of this estimation operation model is experimented. The experimentation comes out more accurate results than the method by linear function.

Key words: Moving Objects, Location Estimation, Cubic Spline Interpolation

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1. Introduction

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.

Sistla and Wolfson[1,2] proposed a method to predict future location of moving objects based on the present location, speed, and direction of the object, but did not present moving location estimation method of the uncertain past moving objects. Pfoser[3] proposed the method, which used the linear interpolation about the uncertain location of moving point objects, which was not sampled. However, there is no mention on the future location estimation method. Besides, Pfoser[4] introduced the modeling method, which used probability and fuzzy set theory about spatiotemporal change of the moving objects. However, he did not show a concrete method of the expression or location estimation for the moving objects. Up to the present, works have been focused on either past or future uncertain location estimation. So they did not propose a method which uses the history information stored in the same database in order to estimate both past and future moving location simultaneously.

Therefore, this paper proposes a method that predicts both past and future locations of the moving object using the same movement information. The past movement information is stored at a regular sampling period at a history database. For the estimation of locations at random period which are not sampled, the piecewise cubic spline interpolation is used, not the traditional linear interpolation.

The description of this paper is as follows. In section 2, we review the concept of the moving object and the processing method of the uncertainty. In section 3, the location estimation function of moving objects are described. In section 4, we describe the algorithms of location estimation functions. In section 5, we analyze the errors of predicted location through the experiments of the proposed location estimation method. In the final section 6, the conclusion and some direction for further research are mentioned.

2. Related Works

Moving objects[2,5,6,7] are the objects of which spatial data are changed in sequence over time. They can be largely divided into moving point and moving region. Moving points are positions or locations changing over time, including people, rocket, missile, tank, submarine, etc. Moving regions are positions as well as shapes of the objects changing over time. These include administrative area, progress of forests, influence of storms, and racial movement. Query for certain time returns points, which describe existing position of the moving object at that time. Query for moving point asks for the position of the moving object, and does not ask about its regions.

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[2].

To solve these problems, Pfoser[3] suggested the method for specifying the moving objects with a relational database and the method for measuring uncertainties with error information. When it expresses the continuous movement of the moving object drawn as a curve by the polyline of the discrete form, the uncertainty occurrence factors of the moving objects were classified into the measured errors and the sampling errors. Furthermore a method to integrate spatiotemporal data and error information into relational database schema was proposed. 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. Nothing about future location estimation method has been mentioned.

Also, Pfoser[4] introduced a modeling method of uncertain changes using probability and the theory of fuzzy sets. That method classifies the elements of the spatiotemporal uncertainty into the spatial object, time point, and time period. Regarding the four sorts of spatiotemporal scenario and change, it suggests the uncertainty processing method of changing function using the fuzzy set or probability. Definition and the method of uncertain location estimation of moving objects using a database are not concrete.

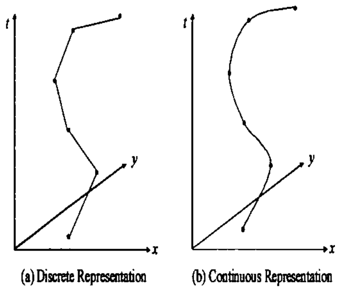
Sistla and Wolfson[1,2] proposed a method to predict the future location of moving objects based on the current location of the object, speed, and direction. The current research of DOMINO refers to the location update policy, and uncertainty of the location related to database specifying. It also suggests 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.

3. Location Estimation of Moving Objects

3.1 Data Model

The positions of moving objects are continuously changing over time. For modeling these moving objects, we can consider both continuous and discrete models. The continuous model allows us to represent the moving object in terms of infinite sets of points, and to view the moving point as *a continuous curve* in the 3D space. This model can accurately describe the motion information, but it is inadequate to be implemented since we cannot store or manipulate infinite points in computer.

On the other hand, the discrete model allows us to describe the moving object in terms of finite sets of points and to view the moving point as *a polyline* in the 3D space. This can be implemented by showing the motion information of the moving object in terms of approximate values. Although the changing positions of the moving object are a continuous concept, is necessary to use the discrete concept for modeling a system that can express these changes of, since computer systems we use have limited resources.



[Fig. 1] Moving Object Model

The location change scenarios of the moving objects are used as a basic tool for evaluating spatiotemporal uncertainty[4]. The location change of the moving objects can occur discretely or continuously, and can be recorded as time points or time periods[3,6].

In this paper, for the process of uncertain location information of moving objects, location is predicted by the past and future locations on the target of continuous location change scenario of the moving objects as shown in [Fig. 1]. Moving objects are assumed to be represented as moving points. The scenario in [Fig. 1] describes the continuously moving objects, and the moving locations of the objects are supposed to be sampled in discrete points. The changes are expressed on the two-dimensional space as x and y coordinates with time axis of t. Thus, it is composed of 3 dimensions. T axis can express the time value of past, present, and future. However, the values stored in the database are actually those of the past and present, and the future is processed by a specific operation.

Moving objects are specified through location estimation function and estimation of uncertain information using a relational database. Database is composed of two relations to store sampled location of moving objects and to have the following schema:

OBJECT (Oid, Code, Name, Type, Etc.)
HISTORY (Code, Time, X, Y)

In OBJECT relation, Oid is the key value as an identifier of the moving object. Code, Name, Type, Etc are for the properties of each object including non-spatial information. Movement information relation, HISTORY, stores historical information regarding sampled time and location of the object. In HISTORY relation, Code describes key value, and Time, X, and Y specifies sampled time point and location coordinate values.

Location information of the moving objects is stored in the database at a regular time period. Location estimation function, which is dependent on time, is used to result in the query about location information of non-sampled past time point of t_k[8,9]. Up to now linear interpolation has mainly been used for location estimation function[3,10,11]. Linear interpolation describes continuous location change between two points with one dimensional function, so every movement of the object is straight during the period. Therefore, with linear interpolation, gradual curved movement as shown in [Fig. 1] can not be expressed. Thus, this paper proposes location estimation function using the piecewise cubic spline interpolation.

3.2 Piecewise Cubic Spline Interpolation

Suppose $\{(x_i, y_i)\}_{i=0}^{N}$ consists of the set of N+1 points. When $a=x_0<x_1<\cdots<x_N=b$ and the coefficient $s_{i,0}, s_{i,1}, s_{i,2}, s_{i,3}$ of N numbers of cubic polynomial $S_i(x)$ meet the following properties, the function $S(x)$ is a cubic spline [12].

Property I: $S(x) = S_i(x) = s_{i,0}+s_{i,1}(x-x_i)+s_{i,2}(x-x_i)^2+s_{i,3}(x-x_i)^3$, $x\in[x_i,\ x_{i+1}],\ i = 0,1,\cdots,N-1$

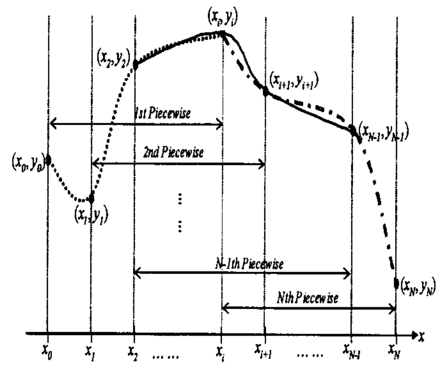
Property II: $S(x_i) = y_i,\ i = 0,1,\cdots,N$

Property III: $S_i(x_{i+1}) = S_{i+1}(x_{i+1})$, $i = 0,1,\cdots,N-2$

Property IV: $S_i'(x_{i+1}) = S_{i+1}'(x_{i+1})$, $i = 0,1,\cdots,N-2$

Property V: $S_i''(x_{i+1}) = S_{i+1}''(x_{i+1})$, $i = 0,1,\cdots,N-2$

Cubic spline interpolation shows the set of points of data as polynomial curves and is used in computer graphics systems. The purpose of this method is to draw flexible curves without the influence of errors in connecting the points. Specific definitions and proof of cubic spline interpolation are described in[12,13,14,15,16].



[Fig. 2] Piecewise Cubic Spline Interpolation

[Fig. 2] describes piecewise cubic spline interpolation. When the set $\{(x_i, y_i)\}_{i=0}^{N}$ composed of $N+1$ numbers of points exists, N numbers of piecewise cubic polynomials are produced. Thus all values of the coordinate, which exist continuously, can be calculated. When a random x value, x_k ranges $x_i<x_k<x_{i+1}$, then y value is found using the 4 points of piecewise cubic spline interpolation polynomials $(x_{i-1}, y_{i-1}), (x_i, y_i), (x_{i+1}, y_{i+1})$, and (x_{i+2}, y_{i+2}).

3.3 Location Estimation Function using the Cubic Spline Interpolation

To predict the uncertain past location of the gradually curved movement, the piecewise cubic spline interpolation is used as follows. The function is used for estimation of location and based on the definitions 1 and 2.

[Definition 1] (*Location Estimation Function*) Location estimation function models the continuous location changes of the moving objects and it returns all locations of the objects within a random time period of $T_i=[t_i, t_{i+1}]$[8]. Location estimation function is described as $LEF: t_k \rightarrow (x_{t_k}, y_{t_k})$, when random time point t_k is inserted and location coordinates (x_{t_k}, y_{t_k}) are produced. In this case, the range of t_k is $t_0 \leq t_k \leq now$. The t_0 is the starting time point stored in the object information relation OBJECT. The *now* is the latest time point stored in the relation HISTORY.

To define the location estimation function *LEF* of a random moving object O_A using cubic spline interpolation, the history set of moving objects is defined as follows. The data of the moving objects are stored in three-dimensional set, which is formulated with two-dimensional spatial information (*x*, *y*) plus one-dimensional time information. However, the location estimation function does not deal with three-dimensional sets but only with two-dimensional set of *x*- and *y*-axis over time.

[Definition 2] (*History set of moving objects*) All P values are the history sets of the random moving object O_A. Then a three-dimensional history set is produced. $P=\{p_0(t_0, x_0, y_0), p_1(t_1, x_1, y_1), \cdots p_n(t_n, x_n, y_n)\}$. In P, $p_0(t_0, x_0, y_0)$ is the location coordinate (x_0, y_0) of time point t_0 that is stored first in the history relation. And $p_n(t_n, x_n, y_n)$ is the location coordinates (x_n, y_n) of time point t_n that is stored the latest. The three-dimensional history set P is divided into two-dimensional sets of x and y over time t. x-axis history set is $P_x=\{p_{x_0}(t_0, x_0), p_{x_1}(t_1, x_1), \cdots p_{x_n}(t_n, x_n)\}$, and y-axis history set is $P_y=\{p_{y_0}(t_0, y_0), p_{y_1}(t_1, y_1), \cdots p_{y_n}(t_n, y_n)\}$.

Based on the definitions 1 and 2, the piecewise cubic spline polynomial in order to find x and y of past random time point t_k can produce two cubic spline functions $x_{t_p}=F_k(t_p)$ and $y_{t_p}=G_k(t_p)$ using two-dimensional history set P_x and P_y. During the random time period of $T_i=[t_i, t_{i+1}]$, $F_k(t_p)$ is the function to find x coordinates of random past time point t_p, which meets the condition of $t_p \in I_k$, $I_k=[t_k, t_{k+1}]$. The function $F_k(t_p)$ is derived as the following Eq. (1)

$$F_k(t_p)=s_{k,0}+s_{k,1}(t_p-t_k)+s_{k,2}(t_p-t_k)^2+s_{k,3}(t_p-t_k)^3 \quad \text{(Eq. 1)}$$

In the Eq. (1), four unknown values

$s_{k,0}, s_{k,1}, s_{k,2}$, and $s_{k,3}$ are included. They are the cubic spline interpolant. This four interpolants can be derived as the following Eq. (2). We apply the proposed method in[12] to the Eq. (1) for the Eq. (2)

$$s_{k,0}=x_k,\ s_{k,1}=d_k-\frac{h_k(2m_k+m_{k+1})}{6},$$
$$s_{k,2}=\frac{m_k}{2},\ s_{k,3}=\frac{m_{k+1}-m_k}{6h_k},$$
$$h_k=t_{k+1}-t_k,\ d_k=\frac{x_{k+1}-x_k}{h_k},$$
$$k=0,1,\cdots,n-1 \qquad \text{(Eq. 2)}$$

To obtain the value of m_k in the Eq. (2), solve the next linear simultaneous equations.

$$(3h_0+2h_1)m_1+h_1m_2=u_1$$
$$h_{k-1}m_{k-1}+2(h_{k-1}+h_k)m_k+h_km_{k+1}=u_k,$$
$$k=2,3,\cdots,n-2$$
$$h_{n-2}m_{n-2}+(2h_{n-1}+3h_{n-1})m_{n-1}=u_{n-1}$$
$$u_k=6(d_k-d_{k-1}),\ k=1,2,\cdots,n-1 \quad \text{(Eq. 3)}$$

Now we can get the values of $m_1, m_2, \cdots$, and m_{n-1} by solved the linear simultaneous equations. The last, the values of m_0 and m_n is needed.

$$m_0=m_1,\ m_n=m_{n-1} \qquad \text{(Eq. 4)}$$

Then the values of $s_{k,0}, s_{k,1}, s_{k,2}$, and $s_{k,3}$ is obtained by applying the value of m_k to the Eq. (2). In the end, the coordinate x_{t_p} of the time point t_p is derived by applying the values of $s_{k,0}, s_{k,1}, s_{k,2}$, and $s_{k,3}$ to the Eq. (1). Next, the function $G_k(t_p)$ is derived as the following Eq. (5)

$$G_k(t_p)=s_{k,0}+s_{k,1}(t_p-t_k)+s_{k,2}(t_p-t_k)^2+s_{k,3}(t_p-t_k)^3 \quad \text{(Eq. 5)}$$

We can solve the Eq. (5) using the three equations (2), (3), and (4).

4. Algorithm for Location Estimation

The location estimation algorithm for random time point t_k, which is not stored in the database, is as follows. The algorithm uses object and history relation mentioned in section 3, and the piecewise cubic spline interpolation polynomial using 4 points is used for the function.

[Algorithm 1] Location Estimation Function

```
Algorithm LE_Function(oid_O, t_p)
Input: oid_O(the identifier of object O_A),
       t_p(random time point)
Output: x_t_p(x value of time point t_p),
        y_t_p(y value of time point t_p)
OBJECT: object information relation,
        HISTORY : history information
        relation
Begin
  If (Oid = oid_O in OBJECT relation) Then
    code ← code value of the object
    If (Code = code and Time = t_p in
       HISTORY relation) Then
       x_t_p ← x value of the searched
tuple
       y_t_p ← y value of the searched
tuple
    Else
```

```
        search four tuples
          (t_{i-1}, x_{i-1}, y_{i-1}), (t_i, x_i, y_i),
          (t_{i+1}, x_{i+1}, y_{i+1}),
          (t_{i+2}, x_{i+2}, y_{i+2}) are satisfied by
        the    condition t_i ≤ t_p ≤ t_{i+1}
      t[0] ← t_{i-1}; t[1] ← t_i;
      t[2] ← t_{i+1};  t[3] ← t_{i+2};
      x[0] ← x_{i-1}; x[1] ← x_i;
      x[2] ← x_{i+1}; x[3] ← x_{i+2};
      y[0] ← y_{i-1}; t[1] ← y_i;
      t[2] ← y_{i+1}; t[3] ← y_{i+2};
      x_t_p ←
  Coord_CubicSplineInterpolation
                (t, x, t_p) //for F_k(t_p)
      y_t_p ←
  Coord_CubicSplineInterpolation
                (t, y, t_p) //for G_k(t_p)
    Else x_t_p and y_t_p ← error value
    return x_t_p and y_t_p
  End
```

The location estimation function (*LE_Function*) described in Algorithm 1 with the input of the 'identifier *oid_O* of the random moving object O_A and the random time point *t_p*, produces the output of the (*x*, *y*) coordinates of *x_t_p* and *y_t_p* at the time point *t_p*. First, check if the input identifier of the object *oid_O* is the instance of Oid, which is stored in object relation. The input identifier is not included in the object information relation OBJECT, assign the error value to the result variable *x_t_p* and *y_t_p*, and finish the function.

In other cases, search the location coordinates of the object at *t_p* time point, which is stored in HISTORY relation. If the location values at *t_p* time point exist in movement information relation, finish the function after converting the searched values to the result. Otherwise, call piecewise cubic spline function and find the values of *x_t_p* and *y_t_p*. In this case, the input *Time* is the values of the 4 points to call the Coord_CubicSplineInterpolation function. *X* and *Y* are *x* and *y* coordinates of the 4 points. The locations of the 4 points are the history tuples of the immediately previous two history tuples of the input time point *t_p* and the immediately following two history tuples. The algorithm to process the spline function is described in [Alg. 2].

[Algorithm 2] Cubic Spline Interpolation Polynomial

```
Algorithm
Coord_CubicSplineInterpolation(time,loc,t_k)
Input: 1) The set of coordinates to produce
          cubic spline polynomial
          :(time[0],loc[0]), (time[1], loc[1]),
          (time[2], loc[2]), (time[3], loc[3])
       2) Random time point t_k
Output: Location value of x or y at a random
        time point t_k(variable:Coord_XorY)
N: The number of input coordinates
   (N = 4 at the start)
Begin
   For i ← 0, N-1
     h[i] ← time[i+1] - time[i];
   For i ← 0, N-3
     m4[i] ← 6 * ((loc[i+2] - loc[i+1]) /
               h[i+1] - (loc[i+1] -l oc[i]) /
               h[i]);
   m1[i] ← h[i];
   m2[0] ← 3 * (h[0] + 2 * h[1]);
   m2[1] ← 3 * (h[2] + 2 * h[1]);
   m3[0] ← h[1];
   For i ← 1, N-3
     m2[i]
```

```
m2[i]-((m1[i]/m2[i-1])*m3[i-1]);
      m4[i]                                     ←
m4[i]-((m1[i]/m2[i-1])*m4[i-1]);
    s[2] ← m4[1]/m2[1];
    s[1] ← (m4[0]-m3[0]*s[2])/m2[0];
    s[0] ← s[1];
    s[3] ← s[2];
    For i ← 0, N-2
      a[i] ← (s[i+1]-s[i])/6*h[i];
      b[i] ← s[i]/2;
      c      [      i      ]                    ←
(loc[i+1]-loc[i])/h[i]-(2*h[i]*s[i]+h[i]*s[i+1])/
6;
      d[i] ← loc[i];
      If (time[i] < t_k < time[i+1]) Then
        Coord_XorY ← d[i]+(t_k-time[i])*(c[i]+
             (t_k-time[i])*(b[i]+a[i]*(t_k-time[i
             ])));
    return Coord_XorY
End
```

To the Coord_CubicSplineInterpolation function of Algorithm 2, the set of coordinates of the 4 points to produce the three-dimensional spline polynomial and the random past time point *t_k* are the inputs. The sets of coordinates of the 4 points are in the form of $(time_0, loc_0)$, $(time_1, loc_1)$, $(time_2, loc_2)$, $(time_3, loc_3)$. In this case, $time_i$ is the time value stored in the history information relation, loc_i is the x or y coordinate values of the location of the moving objects at the time point of $time_i$.

The resulting value of this function is the value stored at the variable *Coord_XorY* and the value at the time point t_k, which is produced from the spline function of input coordinates. The algorithm of Coord_CubicSplineInterpolation function shows the same development as the cubic spline interpolation polynomial. First, calculate the 4 coefficients of spline polynomial: a_i, b_i, c_i, d_i. Using the coefficients and the input coordinates of the 4 points, find x and y values at the time point t_k and return the result.

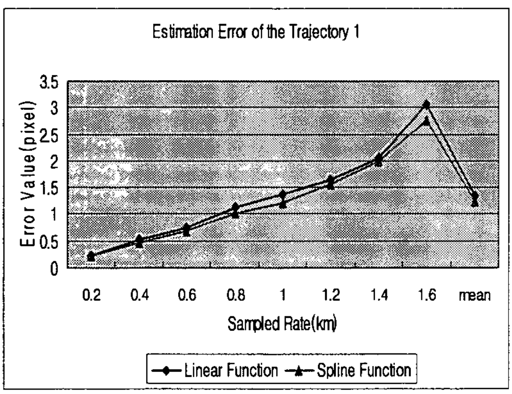
5. Experimental Studies

To analyze the proposed location estimation method of the moving object, an experiment with data samples was carried out. Under the environment of Window XP, JDK1.4 and MS-SQL DBMS were used and JDBC was used to interconnect the databases. The experimental moving object was assumed as a moving point and it was limited to a vehicle moving on a road at a regular speed. For the location estimation experiment to calculate the difference between the predicted location and the actual location, full history information on the trajectory of the experimental target is necessary. Thus, in this experiment two random trajectories on the expressway were chosen and the full location change data on the distant between the two points over time are stored on the database. Trajectory 1 starts from Cheongwon to Shintanjin to Hoideok to Seodaejeon in the middle part of Korea. Trajectory 2 is from Cheongwon to Shintanjin to Hoideok to Okcheon. The total number of tuples is 200. The coordinates system of Java programming language is used and the coordinate measurement is pixel. One pixel is approximately 30m in the real world.

5.1 Result of Past Location Estimation

Location samples of the two trajectories were taken to be compared with the location estimation results and errors from the piecewise cubic spline function proposed in the chapter 3 regarding the location estimation relation about random past time point. Samples were taken by clicking at regular intervals on the users interface map along the trajectory and stored the coordinates in history information relation automatically. The movement time stored in the history relation was stored in accordance with the sampling intervals. Samples were taken at the interval of 0.2km ~ 2.8km for 8 times and stored in different relations.

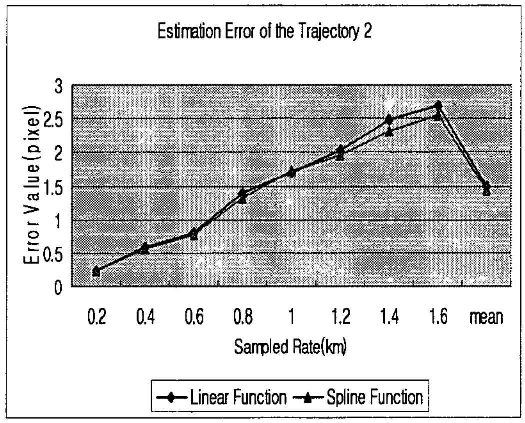
The experiment was about errors in predicting the locations between linear function method and cubic spline interpolation polynomial. The results from the two different methods were compared.



[Fig.3] Error Comparison Graph of Trajectory 1

[Fig. 3] compare the errors in past location estimation results of the samples at the regular intervals using linear function and spline function. The errors were calculated by subtracting the predicted locations values from the actual values stored in the history relation information.

All locations of each sample on the trajectory, which were stored in location change relation, were predicted. [Fig. 3] shows that the errors by the linear function are smaller in the samples between approximately 0.2km and 2.3km. However, in average, the errors by the spline function were smaller.

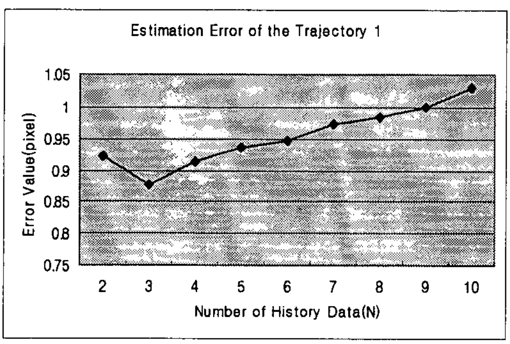


[Fig4] Error Comparison Graph of Trajectory 2

[Fig. 4] are the errors of the samples on trajectory 2 in predicting the past location. On trajectory 2, the error by the linear function is smaller only in the approximately 0.2km samples. In most other samples the errors by the spline function were smaller. From the experiment of predicting the past location on trajectories 1 and 2, we conclude that the piecewise cubic spline function method proposed in this paper is better than the linear interpolation in predicting the past location. Thus, for the comparatively curved route of this experiment, the estimation of the linear interpolation expressed in a straight line is less accurate than the cubic spline interpolation polynomial, which applies different polynomials to the piecewise.

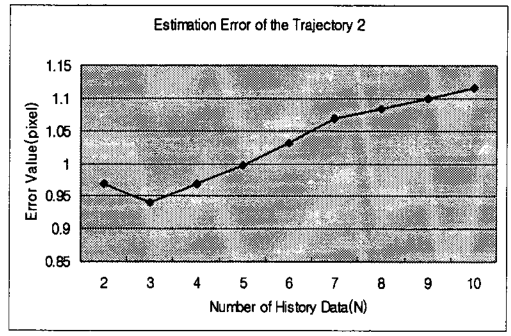
5.2 Result of Future Location Estimation

The moving route relation used in the future location estimation experiment is the same as the history information relation of trajectories 1 and 2 used for the past location estimation. For the error analysis of estimation result using the future location estimation method, and in the future location estimation algorithm which uses the past history object which is variable N, we assigned the values from 2 to 10 for the location, changing the variable N. Random future time point used for the future location estimation was chosen randomly among the stored time values on the history relation. Moreover, we calculated the absolute error of the location values stored in the predicted location and history relation and compared them with the number of the history objects.



[Fig.5] Error Comparison Graph of Trajectory 1

[Fig. 5] on the trajectory 1 shows the predicted result at future time points, in changing the number of history objects from 2 to 10. When the value of N is 3, the error between the predicted result and location stored in the history information relation is the least.



[Fig. 6] Error Comparison Graph of Trajectory 2

[Fig. 6] shows the error value and graph about the future location estimation on the trajectory 2. The trajectories 1 and 2 show the least location estimation errors, when N is 3. If numbers of the history data are large, the location estimation result would be more accurate, whereas in moving routes such as in the trajectories 1 and 2, which are used in this experiment, when the value of N is bigger than 4, the errors produced are larger. However, this does not mean that the error is the least when the number of the history object is 3 in all the moving routes. Due to the characteristics of moving objects' routes, which are applied in different application fields, the value of N becomes changeable.

6. Conclusions

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. Up to now, as studies about the processing of the uncertainty have been focused on the uncertain location estimation of either past or future, they did not suggest a method to predict both past and future moving locations with the same data simultaneously.

Therefore, this paper proposed location estimation functions to forecast both past and future uncertain locations of the moving objects. To predict the location at the past random time point, which was not stored in the database, we used the piecewise cubic spline interpolation. In addition to estimate the location at future random time point, we used the average value of the past moving information. To analyze the characteristics of the proposed functions, location samples were taken from the sample trajectories and were stored in the history relation. We experimented with location estimation of the past and future using sample data.

From the experimentation, we found that the proposed location estimation function using the piecewise cubic spline interpolation was in average smaller than the linear interpolation method. Also, we experimented the future location estimation, changing the number of the past history information. When the number of history information was 3, the location estimation errors were the least. However the optimal value, the number of history information about future location estimation, can be changeable in accordance with the characteristics of the moving object applied in different application fields.

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