The Research of Several Problems of GIS in Designing a Vehicle Navigation System

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Abstract: This paper discusses several problems of GIS in designing a vehicle navigation system (VNS), which do GIS and GPS joint. After a brief introduction of VNS, this article discusses the following issues: (1) How to convert the coordinate data that received by GPS to map coordinate. Because the World Geodetic System is usually used in modern Navigation System (especially in the GPS Navigation System), the longitude and latitude cannot be used in it directly. We must have reference frame conversion and projection conversion. (2) The method of how to display the map in a VNS. The vehicle must be positioned in background map real-time when navigation. Because the spatial and attribute data of road network are very large and complex, but the VNS's CPU is not strong and fast enough, so we have to adapt a special method to fit the need. (3) The matching of GPS data with road network data. Because the GPS signal has error, the vehicle's position cannot be shown in map correctly. We must use the matching technique to correct it for making the vehicle be displayed in right position. Using this technique, we can eliminate the GPS data's error in other direction except along the road. In the other hand, it can also correct the Inertial Navigation System (INS)'s error in VNS.

1 Foreword

It was increase steadily that highway traffic system's complexity and degree of congestion in recent years, especially vehicle ascending rate has far away higher than the road and other facilities of transportation's increment speed. A research found that traffic jam wasted more than 143.5 hundred million liter fuel and 27 hundred million working hours only in American principal city per annum. Since the nineties of the 20th century, these numbers keep on ascending with the speed of 5%-10%

per annum. The traffic control department more and more depends on the new technique to unbar traffic, improve road security, decrease traffic jam and air pollution. Because of the computer and information and communication technology are applied increasingly far and wide, in the future road and vehicle will be changed. This rising field is called Intelligent Transportation System (ITS). Being an important component of ITS, Vehicle Navigation System (VNS) also has a prodigious development.

Usually, a modern vehicle navigation system is composed of several parts or all modules as in figure 1.

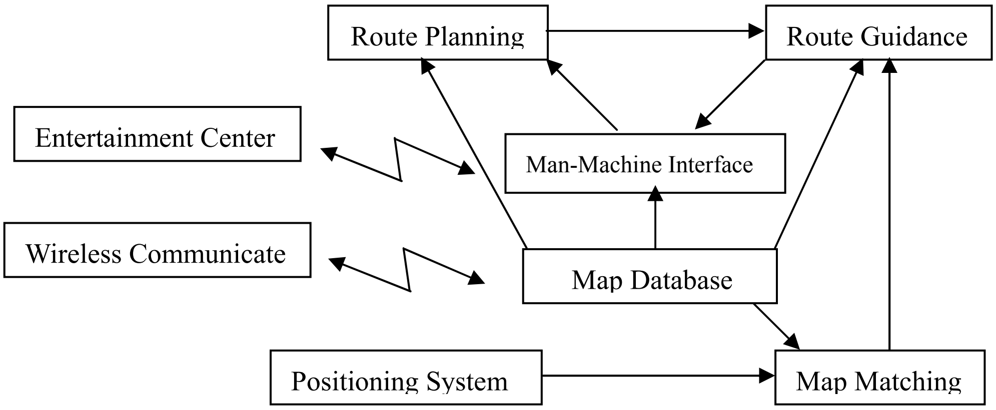

Figure 1 Compose of VNS

From Figure 1 we can know that map database, map matching, route planning and guidance are the kernel in designing a vehicle navigation system. Those functions can be solved in GIS (Geography Information System) perfectly. Thereby, it has huge operation significance that researches the GIS question in designing a vehicle navigation system. In this paper, the following questions are discussed: 1 Converting the coordinate and projection; 2 How to display map in VNS; 3 The matching of GPS data and road data(Map Matching).

2 Coordinates and projection transformation

(1) Convert WGS-84 to BJ-54

In a VNS, the coordinate that GPS used is WGS-84. It was a geocentric coordinate system. But in fact the measurement result was belonging to one state coordinate system or local coordinate system (for instance our state adopted primarily is BJ-54 coordinate system), hence, the GPS positioning results must be transferred to rectangular coordinates.

Transformation model of geotectonic rectangular coordinates usually used Bollsha Model. The transformation formula is:

$$\begin{bmatrix} X_2 \\ Y_2 \\ Z_2 \end{bmatrix} = \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix} + (1+k) \times \begin{bmatrix} 1 & \varepsilon_Z & -\varepsilon_Y \\ -\varepsilon_Z & 1 & \varepsilon_X \\ \varepsilon_Y & -\varepsilon_X & 1 \end{bmatrix} \times \begin{bmatrix} X_1 \\ Y_1 \\ Z_1 \end{bmatrix}$$

In this formula, X_1, Y_1, Z_1, X_2, Y_2, Z_2 are a same point's geotectonic rectangular coordinates that in different coordinates systems. ΔX, ΔY, ΔZ are the grid origin shift factor of the two coordinate systems, k is no dimensional scale factor, ε_X, ε_Y, and ε_Z are twist angle of the axis. In practical applications, these 7 parameters can be resolved by adjusting on control points. If only has one ground control point，it can also be computed ΔX,ΔY and ΔZ only, and cast out ε_X, ε_Y, and ε_Z and k (namely three parametric transformation). Most GPS receiver can set geotectonic rectangular coordinate system that user defined, but it contain nothing but ΔX, ΔY, ΔZ, 3 translation parameters and basic ellipsoidal parameters. It exports directly the geotectonic coordinate or geotectonic rectangular coordinate in the geotectonic rectangular coordinate that user defined. This can elide the coordinate transformation process that user has to do.

It can bring definite error owing to three parametric transformations not take 3 axes twist angle and scale factor. Arguably, this round-off error about geodetic coordinates is:

$$\Delta B'' = -\sin L * \varepsilon_X + \cos L * \varepsilon_Y$$

$$\Delta L'' = tgB * \cos L * \varepsilon_X + tgB * \sin L * \varepsilon_Y - \varepsilon_Z$$

In accordance with the actual measurement, this round-off error is about 10 meters and cannot be neglected. Wherefore, if condition allowed, 7 parameters transformation ought to use.

The data that be transformed to BJ-54 coordinate system are geographic coordinates, here it remains to need convert to plane rectangular coordinate system coordinates. Usually the urban maps that we used are 1:10000 to 1:25000, hence it ought to use 3º belt Gauss-Krruger projection；Whereas maps of regions that used are about 1:500000, it ought to use 6º belt Gauss-Krruger projection.

The transition formulae as follows：

$$x = X_0^B + \frac{1}{2}Ntm_0^2 + \frac{1}{24}(5 - t^2 + 9\eta^2 + 4\eta^2)Ntm_0^4 + \frac{1}{720}(61 - 58t^2 + t^4)Ntm_0^6$$

$$y = Nm^0 + \frac{1}{6}(1 - t^2 + \eta^2)Nm_0^3 + \frac{1}{120}(5 - 18t^2 + t^4 + 14\eta^2 - 58\eta^2 t^2)Nm_0^5$$

In the formulae,

$$X_0^B = C_0B - cosB(C_1 sinB + C_2 sin^3 B + C_3 sin^5 B); t = tanB; l = L - L_0; m_0 = lcosB;$$

$$N = \frac{\alpha}{\sqrt{1 - e^2 sin^2 B}}; \eta^2 = e^2 cosB;$$

L and *B* are latitude and longitude coordinates before transition; *X, Y* are gauss co-ordinate after transition; L_0 is central meridian co-ordinate of projection belt; C_0, C_1, C_2, C_3 are constants that be independent of position of point and nothing but concerned with ellipsoidal parameter. The specific transform method and parameters don't be discussed; please consult professor Yang qihe's "The Transform Theory and Approach of Map Projection".

(2) A practical coordinate system and projection transition method

If each map has some control points, or the map's coordinate system and projection mode are known, those aforesaid methods could meet the demand completely. But at practical work we found, considering security and briefness, some maps are without latitude and longitude and control point. How to join these maps to cartographic database? This method is adopted as follows to solve it.

Above all, it should obtain some particularly point's coordinates and define those points as control points. Wherefore we use GPS to do static measurement 30 minutes in some peculiar points such as road junction, road junction with railway, bridge centre, service station in the roadside, signal construction etc. Then proceed these points (eliminate appreciable error，then calculate average values). These proceeded points could act as maps' control points to register in MapInfo. The specific register method refers to the "MapInfo User Guide".

Through preceded like this, different kinds of coordinate system and projection's map can be converted into WGS-84 coordinate system's data. Navigation system can use it directly. A great deal of experimentation in ZhengZhou, Beijing, Shanghai and other cities prove: if maps' relative location are precise, the data through such method to register and transform could satisfy navigational using, compare with the data that GPS received, the error is less than 10m. Figure 2 is the result.

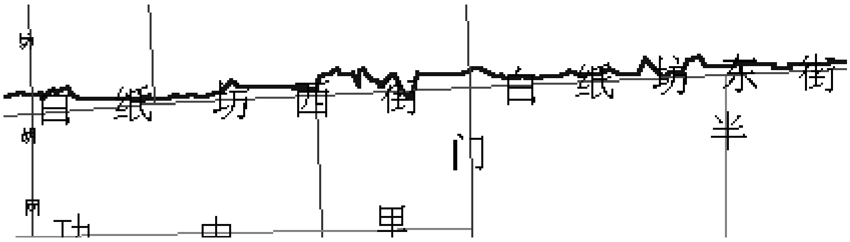

Figure 2: Map data that coordinates has transformed compare with GPS data

3 Display the navigation map

The data of navigation map's characteristic is large data quantity, complicated figure, high accuracy, whereas CPU and storage facility of navigator's velocity are slow and small compare with PC. Wherefore, while only read data from buffer to realize map displaying, maps' display and moving are smooth; but when the data that need to display are not in buffer and it need to reorganize, the display and moving time has already exceeded the time that user can accept. Designing display and moving by conventional method can make the moving course discontinuous and cause frame intermission. Wherefore, we Design double buffer technique and multi-task mechanism to solve this problem.

First of all，two blocks of one size space are applied in RAM as buffer, when the data be read from the first buffer to proceed map moving, at the same time, user's moving direction is judged backstage and next frame's data are organized in the second buffer. If the data in first buffer cannot satisfy the requirement of map moving, the subsequent data is read from second buffer. At the same time, the content of first buffer is abandoned and the data of next frame be reorganized in it. In this way, such work is circulated to ensure the data organization always in background in course of map displaying and moving, as a result, it achieved the map's smooth moving. The schematic diagram is Figure 3.

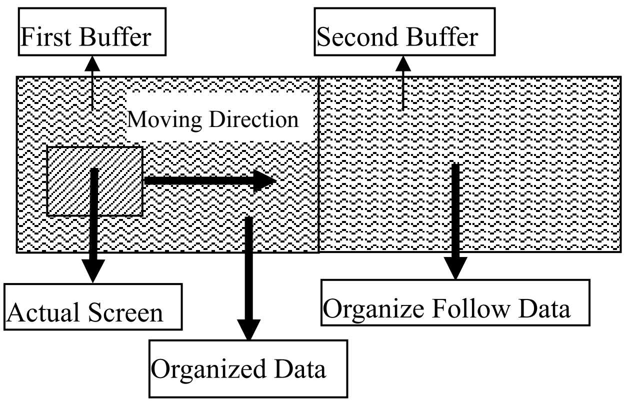

Figure 3: The Schematic Diagram of double buffer technique and multi-task mechanism

4 Map Matching

Presently，the method of vehicle positioning mostly include: Dead-Reckoning, Radio Navigation (as GPS, GLONASS, SIGN-POST etc) and Map-Matching etc. Among those techniques, radio navigation technique depends on other equipments, the positioning accuracy either restricted by the wireless net area of coverage or affected by the accuracy of positioning signal(as GPS). The accuracy of Dead-Reckoning restricted by the accuracy of direction detector and vehicle's velocity pulse unit. In the other hand, it accumulates error and the error increasingly large along with the increase of distance that vehicle running.

Map matching (for short MM), is a software error correction technique, avoided the limitation that those two location techniques cannot overcome. Map matching is technique which can rectify the positioning error of radio navigation or dead reckoning by software approach. This technique is building in pattern recognition theory and based on the hypotheses that "vehicle always running on the road". Figure out precise vehicle position through finding out the road that vehicle on. Which is to say，vehicle's position can be adjusted to absolute location on the map when dead reckoning or GPS indicates vehicle is located on a certain position on the map. Do like this could eliminate accumulated error until next step of map matching. It can get precise vehicle position in real time if this course is done in each consecutive system circle.

In the idiographic realization of algorithmic, following problems are solved: 1, identifying travel road according to history routes; 2, doing projection according to the matching optimal path; 3, decreasing component error utilizing relativity. Following is discussion.

(1) Identifying travel road according to history routes

Map matching could be described below：

The observing values of measuring point are received traveling data, planar stochastic variable s: (x, y). Value x and y are position values that converted to map coordinates. The state space Ω :(w_1，w_2，...... w_c) is stretch state that traveling on a certain precinct of geometric locus or not on current traveling stretch，class identification number C= stretch totality +1，they are variable, relative to the status of current stretch. The state that traveling in a certain stretch w_i:(B, E, state), therein, B: initial point；E: finial point；State: the state of last conjoint stretch.

The similarity measure function λ of No. i stretch that waiting for identify are follows:

$$\lambda_i = q_i * \sum_{k=0}^{N} \Delta_{ik} \qquad 0 \le i. \le c-1$$

$$\Delta_{ik} = \| \vec{s}_{ik} - \vec{v}_{ik} \| = \sqrt{(x_{ik} - xT_{ik})^2 + (y_{ik} - yT_{ik})^2}$$

v:(xT，yT) is vector S:(x,y) to stretch projective point. Δ is plane two dimension euclidean distance,q is weight coefficient. It is evident that smaller λ more similar the stretch.

In order to improve discriminating reliability of stretch, it need to follow a principle: if two stretches almost have alike characteristic or very near，then they neither act as matching stretch nor proceed error rectifying. Such kind of exceptional case should adopt sequence statistical method, to import more observing point to accomplish, as figure 4.

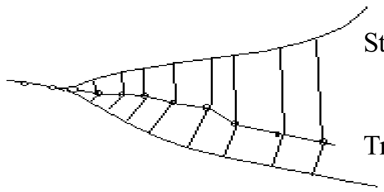

Figure 4: The process of identify

Increasing the value of N, keep on tracking until two stretch's similarity measure function satisfy:

$$\lambda_j - \lambda_i > r * \lambda_j$$

$$\lambda_j > \lambda_i \quad c-1 > i, j > 0,..1 > r > 0$$

It is current traveling stretch if the verdict stretch i satisfy aforesaid two conditions. Here r is adjudicating seclusion factor, it can be set according to practical situation. If no stretch fit this condition, then it can be judged of state of w_c，namely none stretch that traveling on.

It supposed that λa is last stretch's normalization average similarity measure functional value. Adopting indefinitive decision rule to ascertain similarity measure functional weighting factor *q*, the educed coefficient value is weighting parameter *q* that we needed.

(2) Making projection according to matched optimal path

Be known the stretch's slope *k*，then the calculating formula of projective point (x, y) as follows:

$$x = \frac{k(gy - ny) + gx - nx}{\sqrt{k^2 + 1}} + nx$$

$$y = k\left(\frac{k(gy - ny) + gx - nx}{\sqrt{k^2 + 1}}\right) + ny$$

K: stretch's slope; *gx, gy*: Current GPS co-ordinate that received; *nx, ny*: the coordinate of this stretch's start node.

(3) Using relativity to decrease component error

It is observed that aforesaid algorithm can but eliminate the vertical direction of stretch's error ΔY, but cannot eliminate the horizontal direction error ΔX. According to the plentiful surveying result in Peking，ShenZhen and ZhengZhou etc, it found that the relative error's variation is not so large in the received GPS data and same direction stretch in a short period of time, they have goodish relativity. The relativity decision method is using this to rectify the error of traveling direction. The relativity decision method that adopted is turning point information compensation.

The idiographic method is using traveling track to identify turning point, then according to the error rectifying information of previous stretch to rectify current stretch direction's error，until next turning point.

In this method that based on error compensation, the effect depends on right judging of the stretch's transforming, namely turning points judging. Whether a suite of data contain turning point is a pattern recognition problem essentially. In this context, identification solution that based on fuzzy reasoning is being used. Idiographic method as follows：

Importing a degree of dependence function as a characteristic to the identifying result's degree of reliability is the basic characteristic of fuzzy pattern recognition, when using a suite of characteristic value to classify, the result of discriminant function don't give out that it belong to a certain genera but gave out the grade of membership that the characteristic comes from each genera, wherefore, it is characteristic space's soft partition. Specifically, if characteristic vector is $\vec{x}$, class is $X_1, X_2 \cdots, X_m$, then the result of statistical identification is:

$$\vec{x} \in X_i, \qquad \vec{x} \notin X_j \quad j \neq i$$

The result of fuzzy diagnosis is:

$$\begin{pmatrix} X_1 & X_2 & \cdots & X_m \\ \mu_1 & \mu_2 & \cdots & \mu_m \end{pmatrix}$$

In this express:

$\mu_1 + \mu_2 + \cdots + \mu_m = 1$ and $0 \leq \mu_i \leq 1 \qquad i = 1,2,\cdots,m$

If it needs a genus to judge, then it can be taken from the cutset of fuzzy set that has been judged. That is to say it can be judged from a genera that grade of membership is maximal.

For the purpose of vehicle positioning, the fuzzy judgment idea can be imported to improve judging precision when the judgment of turn point is very difficult. It is judged according to a certain rule.

The flow is:

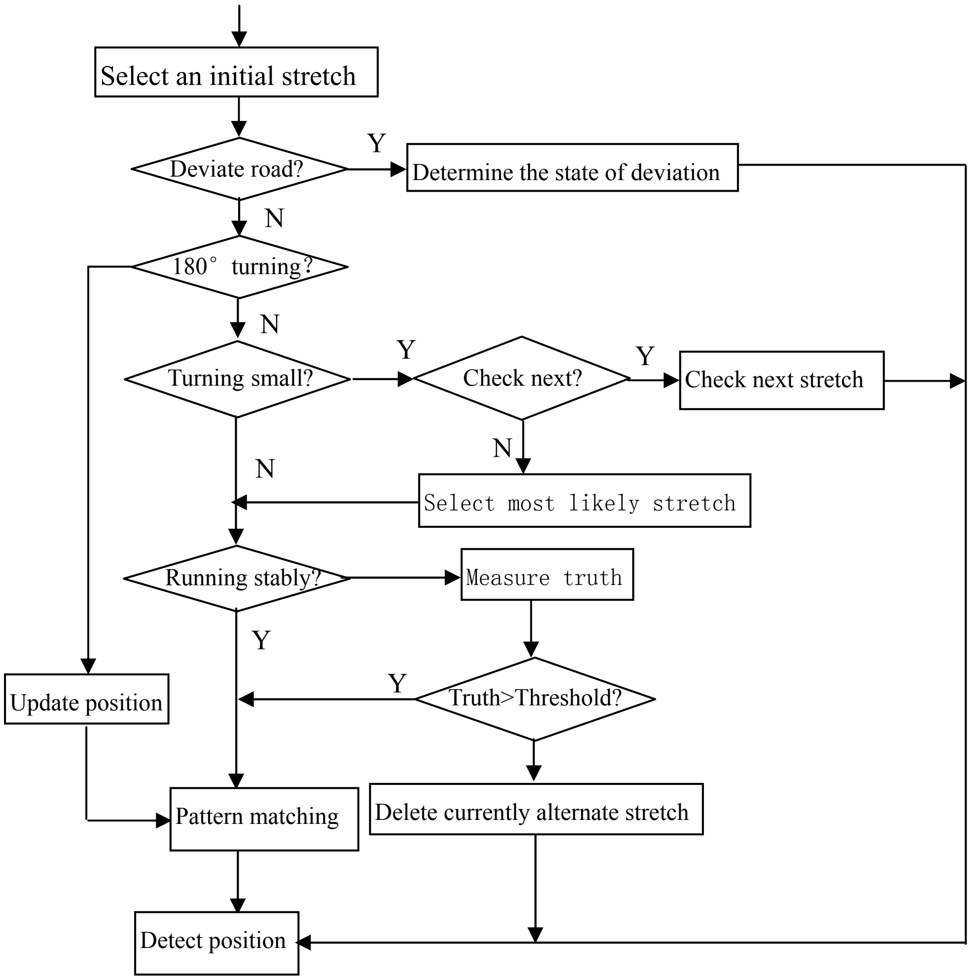

Figure 5: The map matching flow that using fuzzy recognition

Following figure is practical road surveying result that using this method in ZhengZhou.

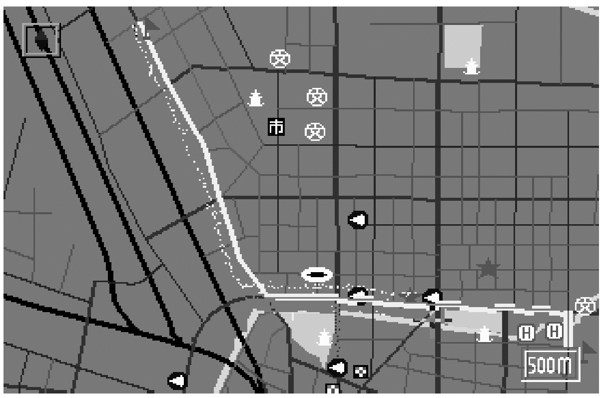

Figure 6: Road surveying result in ZhengZhou

5 Conclusion

Testing in Peking, shanghai Guangzhou and other more than 10 cities shows：

- Aforesaid method could faultlessly carry out in embedded system (74M RISC chip, 16M RAM).
- Displaying and moving map in the course of practical navigation are fluent.
- More than 95% positioning result is matched exactly. The GPS positioning accuracy after matching improves enormously, and it lays the foundation for real-time vehicle tracking and route guidance.
- In the instance that stretch is complicated and map description is simple, this method is still able to kept primary traveling route and reproduction stretch's state truly.
- If the vehicle is counterchecked by the building or cloverleaf junction, navigation system is still able to kept normal operating condition with angular velocity sensor.

Reference:

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