The Construction method of GIS for Autonomous Vehicles

Wang Meiling, Yu Yong, Wang Qizhen, Yang Yi, Liu Tong
School of Automation
Beijing Institute of Technology
Beijing, China
wangml@bit.edu.cn

***Abstract*—In order to achieve the dynamic construction of GIS which shows the environment information around the driving autonomous vehicle, this paper introduces a method, including the data fusion of laser radar, GPS and IMU, the registration of point cloud data, the rasterisation and the extraction of isosurface. The geographic objects which influence the driving characteristics of the autonomous vehicle can be extracted from the processed isosurface according to the analysis of the feature of the autonomous vehicle. This construction method improves some limited ability of GIS, which can provide the navigation information for the autonomous vehicle.**

***Keywords*—GIS, Autonomous vehicle, Geographic objects, Data fusion**

I. INTRODUCTION

At present, the study on GIS in the autonomous vehicle (AV) field mostly focus on urban traffic, but that of the construction of GIS on the field environment is less.

The general geographic data provided by GIS is mostly attracted from the natural characteristic, which describes the spatial feature and attribute feature. However, the autonomous vehicle need more information besides the spatial feature and attribute feature. The throughput capacity, the elusive capacity and other characteristic should take into consideration according to the specific space object. In addition, the accuracy of data is better. So the general geographic data of GIS can't meet the requirements for the autonomous vehicle in the field.

On the other hand, the dynamic update capability of GIS restricts the application on autonomous vehicles. The driving environment information changes dynamically. However, the update cycle is long and the dynamic update capability is limited, because of high cost to update GIS. Due to the lag of the data acquisition and limited data precision, especially in the field, there are many restrains in application of GIS for AV. Therefore, in general, the given GIS can't meet the real-time need for AV.

To sum up, the research of dynamic construction of GIS is more important. When the autonomous vehicle is running, the GIS database is updating dynamically and the environment information can guide the autonomous vehicle at the same time.

II. THE DATA FUSION OF MULTISOURCE

In this paper, the spacial geographical data are obtained by the vehicle-mounted sensors, including cloud points from the laser radar, the geodetic coordinates from GPS and the attitude data from IMU. The dynamic construction diagram is shown in Fig. 1. The cloud points need registration by the data of GPS and IMU, to unify the coordinate system.

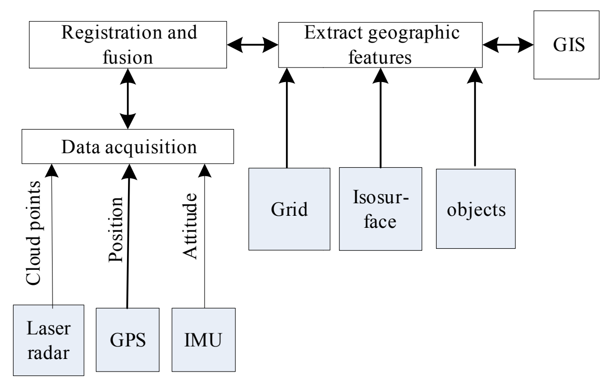

Figure 1. The processing of data

A. The data acquisition

Novatel SPAN-CPT hybrid navigation equipment is one-piece encapsulated. It can provide GPS/IMU combination data, such as the longitude L_{84}, latitude B_{84}, altitude Z_{GPS}, roll angle θ_{roll}, pitch angle θ_{pitch}, yaw angle θ_{yaw}.

The cloud points come from the vehicle-mounted 3D laser radar. Velodyne HDL-64E, used in the experimental AV, has 360°horizontal view, 26.8°vertical view and 5-15Hz optional scan rate. One frame of cloud points acquired in our university yard is shown in 3D form as Fig. 2.

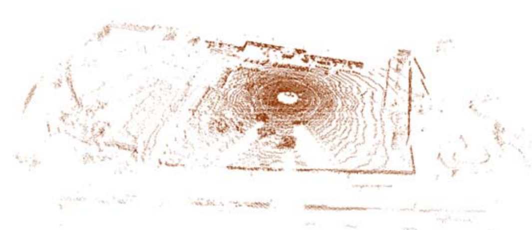

Figure 2. The cloud points

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B. Coordinate transformation

The coordinate system used in GPS is WGS-84, but in China, Beijing-54is adopted in most cases. So WGS-84 coordinates should be transferred to Beijing-54. Because the map and the coordinate system used for GIS is plane, the Beijing-54 ellipsoidal geodetic coordinate system can't be used in the plane map directly. It should be projected on the plane. Gauss-Kruger projection is adopted here，which is an equal-angle projection and has less distortion in smaller range. At the same time, in order to restrict the further distortion International Association of Geodesy divides the globe into several equal longitude zones by the specified longitude range. The coordinate system of Beijing-54 uses Gauss-Kruger projection and divides the whole land area by 3°or 6°longitude range. The X axis of Gauss plane coordinate is the projection of central meridian and the Y axis is the projection of the equator. The origin is the intersection of X axis and Y axis. X value is moved to west for 500 km, to avoid the negative coordinates on the west side of central meridian.

In consideration of the small range of GIS information achieved from the autonomous vehicle, the plane conversion model is enough for practical application as well as simple and reliable. Suppose Beijing-54 and WGS-84 have the same center of ellipsoid and the same axes, the coordinates have the same spatial rectangular coordinates. And we don't need to considerate the translation, rotation and zoom of the coordinate system. So the latitude and longitude coordinates can be transferred to Beijing-54 Gaussian projection coordinate conveniently.

The known semi-major axis and semi-minor axis of the ellipsoid of WGS-84 are a_{84} = 6378137m and b_{84} = 6356752.314m. The axes of the ellipsoid of Beijing-54 (Krasovsky ellipsoid) are a_{54}=6378245m and b_{54}=6356863.019 m.

(1) First, the space rectangular coordinates (*X, Y, Z*) can be computed by putting the longitude and latitude coordinates, a_{84} and b_{84} into formula (1)~(5).

$$e = \sqrt{1-(b/a)^2} \quad (1)$$

$$N = \frac{a}{\sqrt{1-e^2\sin^2 B}} \quad (2)$$

$$X = N\cos B\cos L \quad (3)$$

$$Y = N\cos B\sin L \quad (4)$$

$$Z = N(1-e^2)\sin B \quad (5)$$

(2) Next, get the longitude and altitude B_{54}，L_{54} of Beijng-54 by formula (6)~(18).

$$m = \frac{X^2+Y^2}{a^2} \quad (6)$$

$$n = \frac{(1-e^2)Z^2}{a^2} \quad (7)$$

$$r = \frac{m+n-e^4}{6} \quad (8)$$

$$c = \frac{mne^4}{4} \quad (9)$$

$$A = \frac{\sqrt[3]{(c+r^3)+\sqrt{c(c+2r^3)}}}{r} \quad (10)$$

$$t = r(A+\frac{1}{A}+1) \quad (11)$$

$$q = \sqrt{t^2+me^4} \quad (12)$$

$$p = \frac{e^2(m-t)}{q} \quad (13)$$

$$k = \frac{e^2-p+\sqrt{(e^2-p)^2+4(q+t)}}{2} \quad (14)$$

If $k < e^2$, then

$$k = \frac{e^2+p+\sqrt{(e^2+p)^2-4(q-t)}}{2} \quad (15)$$

$$N = \sqrt{a^2+\frac{{Z_{54}}^2e^2}{(k-e^2)^2}} \quad (16)$$

$$B_{54} = \arcsin\frac{Z}{N(k-e^2)} \quad (17)$$

$$L_{54} = \arctan(Y/X) \quad (18)$$

In the above formulae, a=6378245, b=6356863.019, $e = \sqrt{1-(b/a)^2}$.

(3) Last, the plane coordinates x_{54}, y_{54} of Beijing-54 can be got by the forward Gauss solution as formula (19)~(27).

$$e = \sqrt{1-(b/a)^2} \quad (19)$$

$$e' = \sqrt{(a/b)^2-1} \quad (20)$$

$$T = \tan^2 B_{54} \quad (21)$$

$$C = e'^2\cos^2 B_{54} \quad (22)$$

$$A = (L_{54}-L_O)\cos B_{54} \quad (23)$$

$$M = a[(1-\frac{e^2}{4}-\frac{3e^4}{64}-\frac{5e^6}{256})B_{54}-(\frac{3e^2}{8}+\frac{3e^4}{32}+\frac{45e^6}{1024})\sin 2B_{54}$$
$$+(\frac{15e^4}{256}+\frac{45e^6}{1024})\sin 4B_{54}-\frac{35e^6}{3072}\sin 6B_{54}] \quad (24)$$

$$N = \frac{a}{\sqrt{1-e^2\sin^2 B_{54}}} = \frac{(a^2/b)}{\sqrt{1+e'^2\cos^2 B_{54}}} \quad (25)$$

$$x_{54} = M + N\tan B_{54}\left[\frac{A^2}{2}+(5-T+9C+4C^2)\frac{A^4}{24}\right]$$

$$+(61-58T+T^2+270C-330TC)\frac{A^6}{720} \quad (26)$$

$$y_{54}=500000+N[A+(1-T+C)\frac{A^3}{6}$$

$$+(5-18T+T^2+14C-58TC)\frac{A^5}{120}] \quad (27)$$

Here, a=6378245, b=6356863.019, L_O=117/180.

C. The registering of cloud points

The procession of the registering is to transfer the cloud points to Gauss projection coordinate of Beijing-54. Because the cloud points is some 3D points, the registered cloud points should set the elevation field to store the elevation information.

As shown in Fig. 3, the coordinate of the object point relative to the coordinate of the laser radar is (X_{laser}, Y_{laser}, Z_{laser}). The offset of the origin relative to the GPS position of the autonomous vehicle is (X,Y,Z). The plane coordinate (X_{GPS}, Y_{GPS}) is the deduced value from the longitude and latitude value of GPS. The altitude is Z_{GPS}.

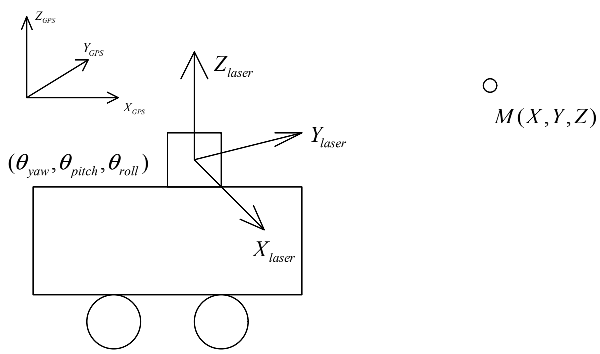

Figure 3. the coordinate system of the vehicle

Then the object point M(X, Y, Z)

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \times \begin{pmatrix} X_{laser} \\ Y_{laser} \\ Z_{laser} \end{pmatrix} + \begin{pmatrix} X_{GPS} \\ Y_{GPS} \\ Z_{GPS} \end{pmatrix} \quad (28)$$

and,

$$a_{11}=\cos\theta_{yaw}\cos\theta_{roll}+\sin\theta_{pitch}\sin\theta_{roll} \quad (29)$$

$$a_{12}=\sin\theta_{yaw}\cos\theta_{roll}-\cos\theta_{yaw}\sin\theta_{pitch}\sin\theta_{roll} \quad (30)$$

$$a_{13}=\cos\theta_{pitch}\sin\theta_{roll} \quad (31)$$

$$a_{21}=-\sin\theta_{yaw}\cos\theta_{pitch} \quad (32)$$

$$a_{22}=\cos\theta_{yaw}\cos\theta_{pitch} \quad (33)$$

$$a_{23}=\sin\theta_{pitch} \quad (34)$$

$$a_{31}=-\cos\theta_{yaw}\sin\theta_{roll}+\sin\theta_{yaw}\sin\theta_{pitch}\sin\theta_{roll} \quad (35)$$

$$a_{32}=-\sin\theta_{yaw}\sin\theta_{roll}-\cos\theta_{yaw}\sin\theta_{pitch}\cos\theta_{roll} \quad (36)$$

$$a_{33}=\cos\theta_{pitch}\cos\theta_{roll} \quad (37)$$

Here, X and Y are the projection coordinates of cloud points in Beijing-54, and Z is the altitude value. These point data is stored in GIS database, and it is convenient for the further processing.

III. THE EXTRACTION OF GEOGRAPHIC FEATURE

In the processing of dynamic construction of GIS, it is important to extract the geographic feature from the surrounding environment. This section introduces a method to construct GIS dynamically. At first, the cloud points are transferred to the grid data. Secondly, the grid data transferred to the isosurface. Finally, the geographic objects are extracted from the isosurface and stored into the spacial database.

A. the generation of grid

The software *Supermap* provides the method of transferring cloud points to grid, *point3DtoDEM()*. In this algorithm, the resolution of grid, which is the length of a side of a grid cell, should be set.

Fig.4 shows the result of DEM through the algorithm *point3DtoDEM*. This figure is extracted from one frame of cloud points acquired in our university yard. The resolution is set as 0.5m. And there are 348*427 cells in the area of 174m * 214m.

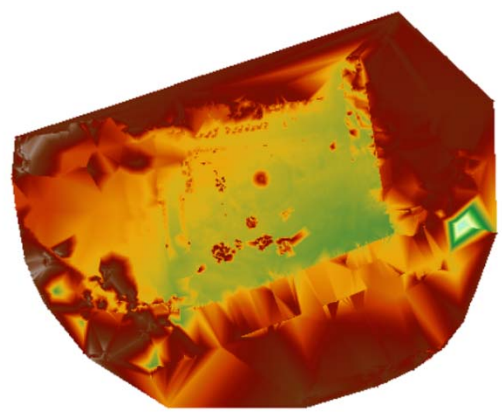

Figure 4. The grid

B. The generation of isosurface

Because the geographic objects expresses in the form of the poly geometry objects, the grid should be transferred to isosurface in order to extract the geographic objects.

The method isoRegion is adopted here. There are two parameters to control the generated isosurface, which are reference value and distance value. The reference value is the initial value to generate the isosurface. And the distance value is the difference between the two adjacent isolines. The parameters decide the number of the isosurfaces. For example, the reference value is set as 0m and the distance value is set as 50 m, the elevation value of grid ranging from 120 m to 999 m can be extracted 16 isosurfaces. The elevation of the isosurface which has the minimum elevation is 150 m, and the maximum is 950 m. The principle of this method is the interpolation algorithm for the grid, connecting the equivalent points and closing down the adjacent isolines.

The generated result of Fig. 4 is shown as Fig. 5. The reference value is the altitude of the autonomous vehicle Z_{GPS}, and the distance value is 0.5 m.

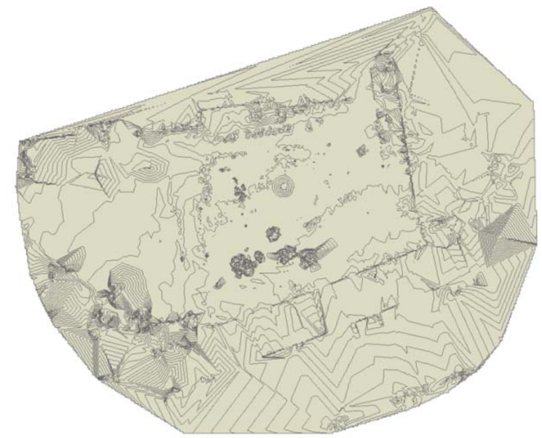

Figure 5. The isosurface

C. *The extractive method of geographic objects*

As described above, the geographic objects can influence the driving characteristics of the autonomous vehicle, so they are also need to be extracted. The geographic objects provide navigation information, so the extractive method should base on the driving parameters of autonomous vehicles. Two parameters, the high threshold and the query range, are set here. The high threshold decides the elevation of extracted objects. The objects whose elevation exceeds a value or bellows a value should be extracted, because these objects will influence the vehicle's traffic ability. Because the accuracy of the cloud points will decrease with the range extension and the cloud points becoming sparse, the query range can determine the range to query in order to control the accuracy.

(1)Parameter setting

The high threshold is the first parameter to be set. Suppose the altitude of the autonomous vehicle as Z_{GPS}, the distance from the GPS antenna and the ground as H, the hight upper limit value for AV ass G_{up}, the lower limit as G_{down}, the elevation of objects as Z.

$$Z> Z_{GPS}+ G_{up}-H \qquad (38)$$

$$Z< Z_{GPS}-G_{down}-H \qquad (39)$$

These objects meet the above formulae will prevent AV from driving.

The query range is the second parameter to be set. Suppose the autonomous vehicle as the center of the circle, the radius as R, the position of AV as (X, Y), and the position of the isosurface as (X_0, Y_0). We can query the objects in this circle by the following formula.

$$(X-X_o)^2+(Y-Y_o)^2<R^2 \qquad (40)$$

(2) The query method

The method provided by *SuperMap* is *query (String attributeFilter, CursorType cursorType)*. The returned value of this method is the query dataset which includes the whole geographic objects.

There are two parameters, *attributeFilter* and *cursorType*. The parameter *attributeFilter* queries attribute information of surface objects. The parameter *cursorType* is the type of the cursor, in order to control the attribute of the record set.

(3) The statement of SQL

1) Transferring the high threshold into SQL.

Each object has an internal range of elevation, from the attribute *minValue* to the attribute *maxValue*. If *minValue* is set as the reference, the formula (38)~(39) can be transferred to the following statement of SQL.

MaxValue > Z_{GPS}-G_{up}-H ,

AND *MinValue*< Z_{GPS}+ G_{down}-H

2) Transferring the query range into SQL.

Query range needs to use the boundary values of the surface objects. The position of a surface object is the rectangular center which is composed by 4 boundaries, as shown in figure 6. As the position of the autonomous vehicle is (*X, Y*), the relative statement of SQL is as the following:

Power((SmSdriN+SmSdriS)/2-*X*, 2)+Power((SmSdriE+ SmSdriW)+2 -*Y*, 2)< Power（*R*, 2）

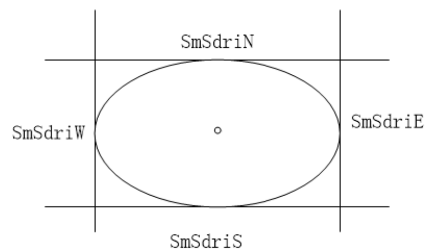

Figure 6. the boundary of the objects

IV. THE EXPERIMENTAL RESULTS

The above method was tested and verified on the autonomous vehicle shown in Fig. 7. The parameters are R=50 m, G_{up} =0.5 m, G_{down} =0.5 m, Z_{GPS}=53.5 m, X=440597.27 m, Y=4425709.55 m.

Figure 7. AV

The extraction result to be stored in GIS database is shown in Fig. 8. The traffic-ability can be deduced from the dynamic GIS database according to the vehicles' characteristics.

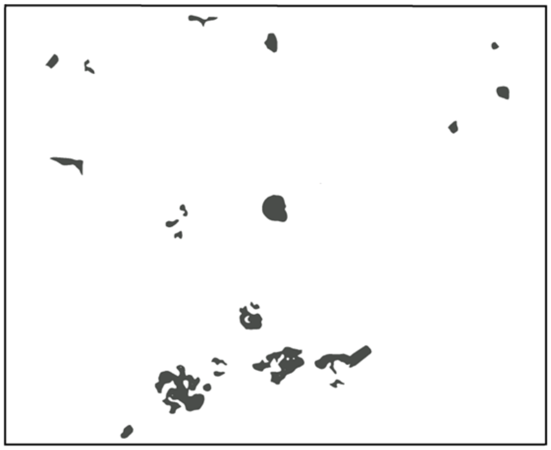

Figure 8. the result of extraction

V. CONCLUSIONS

This paper introduces the method of GIS construction for autonomous vehicles by using the software *SuperMap Objects*. It realizes the data acquisition and the construction of GIS, and it solves the problem that the dynamic update ability is limited. First, the data from these sensors fuse together, and the fused cloud points is projected into Gauss plane coordinate system. And it introduces several methods of data processing in order to extract geographic information from the cloud points, including transferring the cloud points into the grid and the generation of isosurface. We can directly extract the surface objects by the transferring methods. At last, this paper researched the extraction method of geographic objects based on the running features of the autonomous vehicle. The experiments verify the feasibility and practicability of the method.

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