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# Development of GPS Positioning and Navigation Software System Based on VC++

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**Abstract:** With the rapid development of China's economy, the field positioning and navigation technology has also been continuously developed. The global positioning system(GPS), can provide fast and accurate positioning and navigation for exploration operations in desert areas. In this paper, the developed GPS navigation and positioning software system solves the problem of cooperation between GPS user terminal equipment and exploration site. It also effectively combines image processing, data transmission, data processing, error analysis and other technologies to achieve the goals such as data recording and transmission, field navigation, data browsing and query, coordinate transformation, error analysis, and printing curve. After field test work and post-data processing, the software proved to have the following advantages: convenient operation, accurate coordinate transformation and complete functions. It could meet the requirements for accurate GPS positioning and navigation of the field exploration. Its practical effect is good and can provide reference for future field exploration and navigation mapping.

## 1.Foreword

Global Positioning System GPS provides fast and accurate positioning and navigation for exploration operations in desert areas. It is difficult to combine the GPS user terminal equipment with the exploration site work, and to perform an accurately positioning, while expressing the on-site exploration point distribution information. Navigation is essential for the operation of vehicles and personnel in the operation, especially in the deserted environment. The measurement points and measurement routes in the actual measurement process are determined according to the existing map data and the work area information. The operation process is guided by accurate navigation, which will greatly improve work efficiency and provide certain security for the actions of vehicles and personnel. Based on the above requirements, GPS navigation and positioning software is developed for the accurate positioning of GPS and navigation of the exploration process. In addition, for the convenience of users, the software also has functions such as coordinate transformation, error processing analysis, and data browsing query.

## 2.Software Structure

The software system is compiled by Visual C++2017 under Windows 10 system. The development process of GPS navigation and positioning software system is as follows:

The software is combined with the Ag132 car GPS system. The Ag132 provides a data interface, which can be connected to a computer for data transmission. The system receives the positioning coordinate data of the car GPS, and then combines the data with the work area map to record the test positioning data in real time. The vehicle can be navigated in field. In addition, the software can also perform coordinate transformation, error analysis, data curve printout and other processing on the tested data. The software also has other functions such as distance measurement on the data points of the work



area. To facilitate work applications, software systems can also add and present information such as important data points and roads in real time. During the data browsing, the map data and the test data are effectively combined, and data roaming and regional positioning can be performed while the viewing area can be scaled.

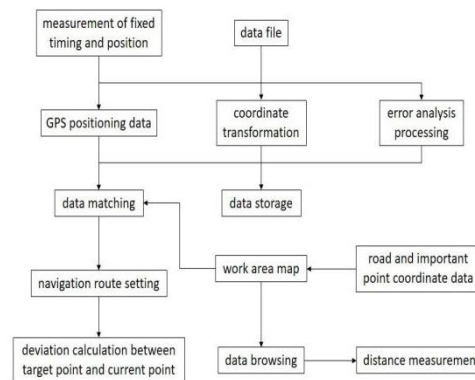


Figure1 GPS navigation and positioning software system diagram

### 3.Map Data Processing

The software system uses the topographic map of the work area as the base map for data projection. Since there is no large-scale electronic map of the work area and DTM (Digital Terrain Model) data, the only 1:100,000 topographic maps(paper) needed to be transformed into a digital map that can be analyzed and processed by computers.

With good vectorization and certain editing capabilities, MAPGIS is a relatively good GIS software developed in China. Scan the paper map of the work area as image data with a scanner, and use MAPGIS to transform the contour lines in the scanned image into descriptive point and line segments. This process is also called the scanned map graphics vectorization. Due to the large capacity of the original paper(such as roads, gullies, surface descriptions, surface vegetation and other data)and loss of valid information caused by the image noise, it is difficult to carry out the graphics vectorization. The contour data can only be interactive vectorized section by section, and sometimes the data must be modified or added according to the original map.

### 4. GPS Positioning Data Acquisition

The Ag132 car GPS system provides a data interface, which can be connected to a computer for data transmission. The system receives data information transmitted by the car GPS and separates the positioning coordinate data. The Ag132 car GPS system can output data in NMEA and RTCM two formats. Since NMEA is in clear format, it is used in general data communication. The data communication of the software also adopts this format.

The NMEA-0183 data formats used in data communication are described as follows:

GGA: satellite positioning information;

GSA: deviation information (GNSS DOP) and satellite status;

RMC: The minimum GNSS information (refers to achieve the purpose of positioning);

VTG: Ground direction and ground speed.

The GGA package contains satellite positioning information, and its in-package data definition and description are as follows:

\$GPGGA,hhmmss.ss,llll.lllll,a,yyyyy.yyyyyy,a,x,x,x.xx,xxxxx,M,x.x,M,x.x,xxxx\*hh<CR><LF>

\$GPGGA: keywords (GGA package);

Hhmmss.ss: positioning time, adopting the standard positioning time (UTC) format: hourhour, minuteminutessecondsecond.secondsecond (hhmmss.ss);

Llll.lllll: latitude, format: degree degree minute minute. minute minute minute minute minute  
(ddmm.mmmmm)

a: latitude, northern hemisphere (N) or southern hemisphere (S);

yyyyy.yyyyy: longitude, format: degree degree minute minute. minute minute minute minute  
(ddmm.mmmmm);

a: longitude, east (E) hemisphere or west (W) hemisphere;

x: GPS quality, 0 is untargeted or invalid positioning, 1 is GPS SPS positioning format (SPS is commercial format), 2 is deviation correction GPS SPS format (DGPS), 3 is GPS PPS format (PPS is military format) );

x: the number of satellites used;

x.xx: (HDOP) horizontal DOP value;

xxxxx: altitude;

M: altitude, meter;

x.x: height difference of geoid

M: height, meter;

x.x: DGPS signal valid time, the number of seconds since the last valid signal (if there is no DGPS, the number is 0);

xxxx: DGPS reference base station code;

\*hh: The sum check code.

The following is a complete GPS positioning data segment of the Ag132 car GPS test:

\$GPGGA,025259.00,4133.443540,N,08835.897860,E,2,07,1.1,1484.90,M,-57.35,M,1.2,0000\*5C

\$GPVTG,0.0,T,,000.00,N,000.00,K,D\*45

\$GPGSA,M,3,06,10,13,17,23,24,26,,,,,2.0,1.1,1.7\*3A

\$GPRMC,025259,A,4133.443540,N,08835.897860,E,000.00,0.0,180800,1.8,E,D\*26

The computer communicates with the Ag132 car GPS in serial mode. The RS-232 interface is used for data transmission. The serial port data acquisition adopts the query mode. The GGA data packet is separated according to the data package, and the contents of each data segment in the packet are separated and processed to extract GPS positioning coordinate data.

## 5 coordinate transformation

### 5.1 Mutual transformation between space Cartesian coordinate system and geodetic coordinate system

The Earth coordinate system adopts two forms: the spatial rectangular coordinate system and the geodetic coordinate system. The geocentric space Cartesian coordinate system is: the origin O coincides with the Earth's centroid, and the X axis points to the intersection E of the Greenwich flat meridian and the Earth's equator, and the Y axis is perpendicular to the XOZ plane to form the right-handed coordinate system while the Z-axis points to the Earth's North Pole. The geocentric coordinate system is: the center of the earth ellipsoid coincides with the centroid of the earth. The short axis of the ellipsoid coincides with the rotation axis of the earth. The height H is the distance from the ground point to the ellipsoid along the ellipsoid normal. The latitude B of the earth is the angle between the ellipsoid normal passing through the ground point and the equatorial plane of the ellipsoid, and the longitude L of the earth is the angle between the ellipsoid meridian plane passing the ground point and the meridian plane of the Greenwich flat. The coordinates of any ground point T in the earth coordinate system are expressed as (X, Y, Z) or (B, L, H). The conversion relationship between the two coordinates is as follows:

$$X = (N+H) \cos B \cos L$$

$$Y = (N+H) \cos B \sin L$$

$$Z = [N(1-e^2) + H] \sin B \quad (5.1)$$

In the above formula,  $e$  is the first eccentricity of the ellipsoid, and  $N$  is the radius of curvature in prime vertical. If  $a$  represents the long radius of the ellipsoid and  $f$  is the ellipsoidal flatness, then there has a formula:

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

$$e^2 = 2f - f^2 \quad (5.2)$$

When transformed from spatial Cartesian coordinates to geodetic coordinates, the following formula is usually used:

$$l = tg^{-1}(y/x)$$

$$b = tg^{-1}\left[\frac{z}{r(1-E)}\right]$$

$$h = (r^2 + (z + Ne^2 \sin b)^2)^{\frac{1}{2}} - N \quad (5.3)$$

In the formula:

$$e^2 = 2f - f^2$$

$$r = (x^2 + y^2)^{\frac{1}{2}}$$

$$R = (r^2 + z^2)^{\frac{1}{2}}$$

$$k = \frac{R}{a} - \frac{(1-f)}{(1 - \frac{e^2 r^2}{R^2})^{\frac{1}{2}}}$$

$$E = \frac{e^2}{1 + K(1 - \frac{e^2 z^2}{R^2})^{\frac{1}{2}}}$$

$$N = \frac{a}{(1 - e^2 \sin^2 b)^{\frac{1}{2}}} \quad (5.4)$$

When the earth latitude is calculated by the above formula, iterative method (successive approach method) is generally used.

### 5.2 Mutual transformation of space Cartesian coordinate system (Bursa seven-parameter transformation model)

The transformation of space rectangular coordinate of the coordinate system 2 to the coordinate rectangular coordinate transformation of the coordinate system 1 is calculated as follows:

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix}_{\text{Coordinate 1}} = \begin{pmatrix} x_0 \\ y_0 \\ z_0 \end{pmatrix} + kR_x(\theta_x)R_y(\theta_y)R_z(\theta_z) \begin{pmatrix} x \\ y \\ z \end{pmatrix}_{\text{Coordinate 2}} \quad (5.5)$$

In the formula, the (x, y, z) coordinate 1 and the (x, y, z) coordinate 2 are the coordinates of the same point in two different coordinate systems, and  $x_0$ ,  $y_0$ , and  $z_0$  are the origins of the coordinate system 2 in the coordinate system 1. The coordinate value.  $R_x$ ,  $R_y$ , and  $R_z$  are rotation matrices around the x-axis, y-axis, and z-axis. The definition is as follows:

$$R_x(\theta_x) = \begin{pmatrix} \cos \theta_x & \sin \theta_x & 0 \\ -\sin \theta_x & \cos \theta_x & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$R_y(\theta_y) = \begin{pmatrix} \cos \theta_y & 0 & -\sin \theta_y \\ 0 & 1 & 0 \\ \sin \theta_y & 0 & \cos \theta_y \end{pmatrix}$$

$$R_z(\theta_z) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos \theta_z & \sin \theta_z \\ 0 & -\sin \theta_z & \cos \theta_z \end{pmatrix} \quad (5.6)$$

If only the transformation seven parameters of coordinate system 2 to the coordinate system 1 are known, and the transformation seven parameters of coordinate system 1 to the coordinate system 2 are unknown, the above formula can be transformed to find the equation coefficient inverse matrix. Use the transformation seven parameters of coordinate system 2 to the coordinate system 1 to transform the spatial rectangular coordinates of coordinate system 1 to spatial rectangular coordinates of coordinate system 2.

### 5.3 Transformation of Gauss plane rectangular coordinates and latitude and longitude coordinates in BJ54 coordinate system

For the BJ54 coordinate system, the transformation of the geodetic latitude and longitude coordinates to the Gauss plane rectangular coordinate is as follows:

$$x = X + \frac{N}{2}tm^2 + \frac{N}{24}tm^4(5-t^2+9\eta^2+4\eta^4) + \frac{N}{720}tm^6(61-58t^2+t^4)$$

$$y = Nm + \frac{N}{6}m^3(1-t^2+\eta^2) + \frac{N}{120}m^5(5-18t^2+t^4 + 14\eta^2 - 58t^2\eta^2) + 500000 \quad (5.7)$$

In the formula:

$$X = 111134.8611B - (32005.7799 \sin B + 133.9238 \sin^3 B + 0.6976 \sin^5 B - 0.0039 \sin^7 B) \cos B$$

$$N = \frac{a_{54}}{(1 - e^2 \sin^2 b)^{\frac{1}{2}}}$$

$$\begin{aligned}
 e^2 &= 2f_{54} - f_{54}^2 \\
 \eta^2 &= \frac{e^2 \sin B \cos B}{1 - e^2} \\
 t &= tgB \\
 L &= (l - L_0) \\
 m &= L \cos B
 \end{aligned} \tag{5.8}$$

The Gauss plane rectangular coordinate transformation to the earth latitude and longitude coordinates is calculated as follows:

$$\begin{aligned}
 L &= L_0 + \frac{y}{N \cos B_f} - \frac{y^3(1 + 2t_f^2 + \eta^2)}{6N_f^3 \cos B_f} \\
 &\quad + \frac{y^5(5 + 28t_f^2 + 24t_f^4 + 6\eta^2 + 8\eta^2 t_f^2)}{120N_f^5 \cos B_f} \\
 B &= B_f - \frac{t_f y^2}{2M_f N_f} + \frac{t_f y^4}{24M_f N_f^3} (5 + 3t_f^2 + \eta_f^2 - 9\eta_f^2 t_f^2) \\
 &\quad - \frac{t_f y^6}{720M_f N_f^5} (61 + 90t_f^2 + 45t_f^4)
 \end{aligned}$$

In the formula:  $B_f$  is the bottom latitude and can be iteratively calculated as follows:

$$\begin{aligned}
 B_0 &= \frac{x}{111134.8611} \\
 B_f &= B_0 + \sin B_f \cos B_f \\
 &\quad \frac{(32005.7799 + 133.9238 \sin^2 B_f + 0.6973 \sin^4 B_f + 0.0039 \sin^6 B_f)}{111134.8611} \tag{5.9}
 \end{aligned}$$

When  $|B_f^{(i+1)} - B_f^{(i)}| < 10^{-8}$ , the iteration can be stopped. Taking the last iteration as results and other parameters in the calculation formula are defined:

$$\begin{aligned}
 M_f &= \frac{a_{54}(1 - e^2)}{(1 - e^2 \sin^2 B_f)^{\frac{3}{2}}} \\
 N_f &= \frac{a_{54}}{(1 - e^2 \sin^2 B_f)^{\frac{1}{2}}} \\
 e^2 &= 2f_{54} - f_{54}^2 \\
 \eta^2 &= \frac{e^2 \sin B \cos B}{1 - e^2}
 \end{aligned}$$

$$t_f = tgB_f \quad (5.10)$$

#### 5.4 BJ54 Gaussian plane rectangular coordinate and WGS84 coordinate conversion

The coordinate system used by the GPS system Ag132 uses the WGS84 coordinate system. The WGS84 coordinate system is used by the US GPS satellite tracking station while China uses the BJ54 coordinate system and the Gauss plane rectangular coordinate system. The existing control point results also adopt the Gauss plane rectangular coordinate system. In order to establish the base station to input accurate coordinates and measure the comparison data results, the two sets of coordinate systems are mutually transformed.

The transformation of the BJ54 coordinate system to the WGS84 coordinate system is calculated as follows:

$(x, y, h) \rightarrow (L, B, h) \rightarrow (X, Y, Z) \rightarrow (XD, YD, ZD) \rightarrow (LD, BD, hD)$   
among them:

$(x, y, h)$  - the Gauss plane rectangular coordinate and the earth height of the BJ54 coordinate system;  
 $(L, B, h)$  - earth longitude, geodetic latitude and geodetic height of the BJ54 coordinate system;  
 $(X, Y, Z)$  - spatial rectangular coordinates of the BJ54 coordinate system;  
 $(XD, YD, ZD)$  - spatial rectangular coordinates of the WGS84 coordinate system;  
 $(LD, BD, hD)$  - Earth longitude, geodetic latitude and geodetic height of the WGS84 coordinate system.

According to the above steps, the BJ54 Gauss rectangular coordinate can be transformed into WGS84 coordinate, and the process could be inversed.

## 6. Error Analysis and Processing

In general, the true value of the GPS test point is unknown. For test points with high precision requirements, multiple sets of data can be tested, and all test values are averaged to obtain the most probable value, which is approximated as a true value.

$$\bar{x} = \frac{1}{n} \sum_{i=1}^n x_i$$

$$\bar{y} = \frac{1}{n} \sum_{i=1}^n y_i \quad (6.1)$$

During the work process, only a few data values may be measured for each test point. In order to verify the positioning accuracy of the test system, multiple sets of data are tested at several triangular control points of the true position coordinates of known positions, and the measurement data is subjected to errors analysis and processing.

The mean square error of the coordinate components is calculated as follows:

$$\sigma_x = \sqrt{\frac{\sum_{i=1}^n (x_i - x_0)^2}{n}}$$

$$\sigma_y = \sqrt{\frac{\sum_{i=1}^n (y_i - y_0)^2}{n}} \quad (6.2)$$



In the formula,  $x_i, y_i$  is the test data value of the test point, and the  $x_0, y_0$  is the test mean value or the data true value of the multi-group data of the position point.  $\sigma_x, \sigma_y$  is the mean square error of test data in X and Y coordinates.

The mean square error of the true distance of the position is calculated as follows:

$$\sigma_p = \sqrt{\frac{\sum_{i=1}^n [(x_i - x_0)^2 + (y_i - y_0)^2]}{n}} = \sqrt{\sigma_x^2 + \sigma_y^2} \quad (6.3)$$

In the formula,  $x_i, y_i$  is the test data value of the test point, and  $x_0, y_0$  is the true value or the test mean value of the position point data.  $\sigma_x, \sigma_y$  is the mean square error of the test data and  $\sigma_p$  is the mean square error between the test data and the true data value.

In order to reflect the distribution range of test error, it is necessary to calculate the proportion of data points in different error data segments in the total test data points, and the calculation method is as follows:

$$\eta = \frac{N_i}{N} \times 100\% \quad (6.4)$$

$N_i$  is the number of test data points of a certain error data segment, and  $N$  is the total number of test data points.

## 7. Software Design

The software system is compiled in Visual C++2017 under Windows 10 environment. It is divided into three modules: coordinate conversion module, navigation module, error analysis and processing module. The navigation module is the main module, and the other two are subordinate modules. Each module independently forms different executable files, which can be executed and applied separately, and the navigation module can direct the other two modules.

### 7.1 Navigation module

The navigation module adopts the document view structure and divides the window. The main view is used to perform data representation, and the subordinate view serves as a control window. At the same time, the system can also execute some control orders through menus and toolbars. In order to display the map coordinate information of the system mouse during the moving process in real time, the system uses DialogBar to display the BJ54 Gaussian plane rectangular coordinate and the WGS84 coordinate of the current mouse position. The system menu, toolbar and controls in the DialogBar are arranged as shown below:

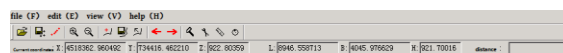


Figure2 Toolbar and display control map

The control window is divided into three parts. The upper part is the thumbnail of the elevation map of the currently used topographic map. The area enclosed by the rectangle in the figure is the terrain data displayed by the current main window; the second part is the control bar, which contains data measurement and display. Basic control such as navigation path setting; the lower part shows the basic information of the navigation process, its distribution and structure are shown in Figure 3:

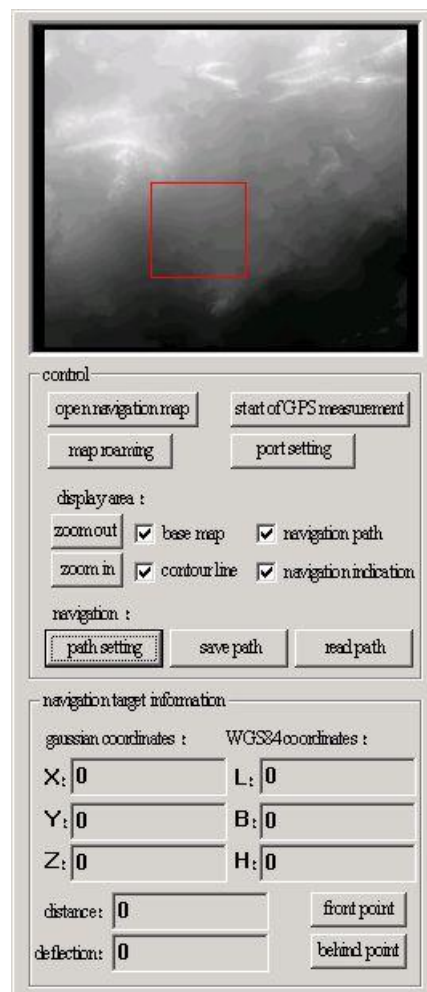


Figure 3 Control window

The navigation module has the following main functions:

1. The system can use different terrain data as a data projection map for measurement and navigation. During the data measurement process, the main display window is automatically adjusted to the current test area, and the display area range can be scaled, while the current test coordinate data is displayed in the DialogBar. During the dynamic test, the main display window tracks the test data, and will automatically display area.
2. GPS test data is saved as a text file. The original test data can be opened by the toolbar button to reappear the test record process.
3. During the test recording process, if you need to restart the test, the system will automatically prompt for data saving.
4. The navigation route setting can be performed by the mouse in the main display window, and the display area can be adjusted according to the change of the navigation path setting.
5. Set the navigation route to save and read it later.
6. For the control points on the navigation path, the current target point can be selected by the front point and the back point control, the selection process is the circumduction selection, and the target point coordinate information is displayed at the same time. During the test navigation process, the distance and the off angle of the current test point from the target point may also be displayed, and the current test point and the target point are marked with a navigation indicator line.

7. For the convenience of users, the system can measure the distance of any two points in the display area. The main display window can adjust the display content, including terrain grayscale map, contour line, navigation path, navigation indication and so on.

### 7.2 coordinate transformation module

The coordinate transformation module also uses document view to segment the window structure. It is mainly divided into two left and right operation windows. The left window is the data to be processed, the right window is the data processing result. The left window supports the operations of data entry, editing, cutting, and pasting, and it can also directly open the data file for processing. The coordinate transformation module can be used alone or as a navigation module.

The coordinate transformation parameters may be different for different work areas. For general considerations, the software can set transformation parameters for different areas.

### 7.3 Error Analysis and Processing Module

In order to verify the measurement accuracy of the GPS positioning system, an error analysis and processing module is designed. The error processing can be performed on multiple sets of measurement data of the measurement points, and the corresponding error curve can be drawn. The software also has print preview and print functions.

The figure below shows the results of data analysis of the relative test data mean and data true value:

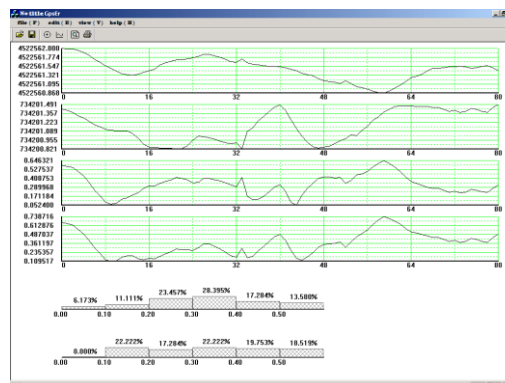


Figure4 Error Analysis Results of Relative Mean and True Values

## 8. Conclusion

The developed GPS navigation and positioning software system effectively combines image processing, data transmission, data processing, error analysis and other technologies to realize goals such as field navigation, data transmission and recording, data browsing query, coordinate transformation, error analysis, curve printing, etc. After application of field test work and post-data processing, the software has the characteristics of convenient operation, accurate coordinate transformation and complete functions. It meets the requirements for accurate GPS positioning and navigation of field exploration process, and achieves the expected effect.

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