SIMULATION OF SHIP-BORNE GPS NAVIGATOR
BASED ON VIRTUAL NAVIGATION ENVIRONMENT

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ABSTRACT. *In the laboratory of maritime college, the real GPS navigator cannot be used in the training of ship navigation due to the fixed position. In order to reduce the expense of training, it is essential to develop a simulator of GPS navigator. Through performing research on Great Circle Track, the problem of calculating an uncertain waypoint by way of a certain waypoint is settled down. In the calculation of navigation route, the parameters related to the voyage between different waypoints can be got. Through analyzing the difference between the WGS 84 coordination and others, the problem on transformation of ship's position is solved. The simulator of FURUNO GP-150 navigator is developed by way of Microsoft Visual Studio 2010. The waypoints and routes are managed with the database by way of the ADO access technology. The operation of simulator is the same to the real equipment and the user interface is friendly. Through testing, the GPS simulator can meet the requirements of training and has been used in the training.*
Keywords: GPS, Waypoint calculation, Route planning, Database access

1. **Introduction.** Operating GPS navigator smoothly for seafarers is a basic skill to make sure of the safety of navigation. The Maritime Safety Administration of the People's Republic of China issues the "Seafarers Competence Assessment Standards of China" [1], which describes the operational ability of GPS navigator for seafarers. Due to lack of money and space, there are not enough GPS navigators for training in most of the maritime colleges. Also, the antenna position of GPS navigator is fixed in the laboratory so that the vessel always enters quiescent state without speed and course. Due to the fixed position, several important functions of GPS navigator are unavailable and the students cannot perform training on these functions effectively. Though some maritime colleges developed simulator of GPS navigator, the type of simulator is so old that it is not used commonly on board. It is urgent to develop a mainstream type of simulator of GPS navigator for training.

GPS navigator can be used for timing, fixing position and navigation on board globally. It is the most important sensor on board which can supply the essential information to the integrated bridge system for navigation. Based on previous research [2-7], the simulator of FURUNO GP-150 GPS navigator is developed by way of Microsoft Visual Studio 2010. It is designed from appearance, function, operation surface to internal software structure according to the real equipment. Through performing research on Great Circle Track, the problem of calculating an uncertain waypoint by way of a certain waypoint is settled down. The transformation relationship between WGS-84 coordinate system and others is analyzed in order to improve the accuracy of positioning. The ADO access technology is employed to improve efficiency of data storage and access. The simulator of GPS navigator enhances the training quality and reduces the cost of training. Through testing, the operation of simulator is the same to the real equipment and the user interface is friendly, the GPS simulator can meet the requirements of training and has

been used in the intelligent scoring system of navigational instrument operation training. The developing technology and experience would be very useful for the simulation of other navigation instruments.

2. Main Key Techniques.

2.1. **Waypoint calculation.** The waypoints are essential elements to navigate the ship by way of GPS navigator. Waypoint setting of GPS is the cornerstone of route planning. So the calculation on waypoints is very important for the simulation of GPS navigator. The Great Circle Track is the closest way between two waypoints on the earth. So the calculation on waypoints and routes is based on the Great Circle Track.

Usually, there are three methods [8] to calculate the great circle, such as great circle chart method, arc to chord correction method and formula computation method. The formula computation method is very simple for programming so that it is adopted in the simulation of GPS navigator. If the position of one waypoint is known, the position of another waypoint can be calculated according to the range and bearing between them in navigator of FURUNO GP-150.

It is assumed that the latitude of starting waypoint is φ_1, and the longitude is λ_1. If the relative range S and relative bearing C are known, the position of destination waypoint (φ_2, λ_2) can be calculated [9] by Formulas (1), (2) and (3).

$$\varphi_2 = \arcsin\left(\sin\varphi_1 \cos(S/60) + \cos\varphi_1 \sin(S/60)\cos C\right) \tag{1}$$

$$\Delta\lambda = \arctan\left\{\frac{\sin(S/60)\sin(C)\cos(\varphi_1)}{\cos(S/60) - \sin(\varphi_1)\sin(\varphi_2)}\right\} \tag{2}$$

$$\lambda_2 = \lambda_1 + \Delta\lambda \tag{3}$$

where

$$\Delta\lambda = \begin{cases} \Delta\lambda & \cos(S/60)\sin(\varphi_1)\sin(\varphi_2) \geq 0 \\ 180° + \Delta\lambda & \cos(S/60)\sin(\varphi_1)\sin(\varphi_2) < 0 \end{cases}$$

Figure 1 shows the interface of waypoints calculation based on range and bearing in the simulator of FURUNO GP-150 navigator.

(a)   (b)

FIGURE 1. Range and bearing to position

2.2. **Route planning.** Route planning must be done before using the GPS navigator to navigate the ship. So the route planning is a key module in the simulator of GPS navigator. The formulas on Great Circle Track are adopted to calculate the certain trip between two waypoints. The total trip can be got through accumulation. According to ship's speed, the parameter of TTG (Time To Go) can be calculated.

Suppose the latitudes and longitudes of two waypoints are known as (φ_1, λ_1) and (φ_2, λ_2). The trip S between the two waypoints can be calculated [8] by way of Formula (4). The predicted course C_1 can be got through Formula (5).

$$S = R \cdot \arccos\left(\frac{\sin\varphi_1 \sin\varphi_2 + \cos\varphi_1 \cos\varphi_2 \cos D\lambda}{1.852}\right) \quad (4)$$

$$C_1 = \arctan\left(\frac{\sin D\lambda}{\cos\varphi_1 \tan\varphi_2 - \sin\varphi_1 \cos D\lambda}\right) \quad (5)$$

where, R is the radius of the earth.

$$R = \frac{360 \times 60'}{2\pi} = 6366.707\text{Km};$$

where, $D\lambda$ is the difference of longitude

$$D\lambda = \begin{cases} \lambda_2 - \lambda_1 & |\lambda_2 - \lambda_1| \leq 180° \\ -(360 - |\lambda_2 - \lambda_1|) & |\lambda_2 - \lambda_1| > 180° \end{cases}$$

In the simulator of FURUNO GP-150 GPS receiver, the waypoints NO.001 and NO.002 are selected to make a navigation route. Through calculating, the trip between the two waypoints is 600 nautical mile. If the ship's speed is 10.0 knots, the navigation time between two waypoints (TTG) can be calculated as Figure 2.
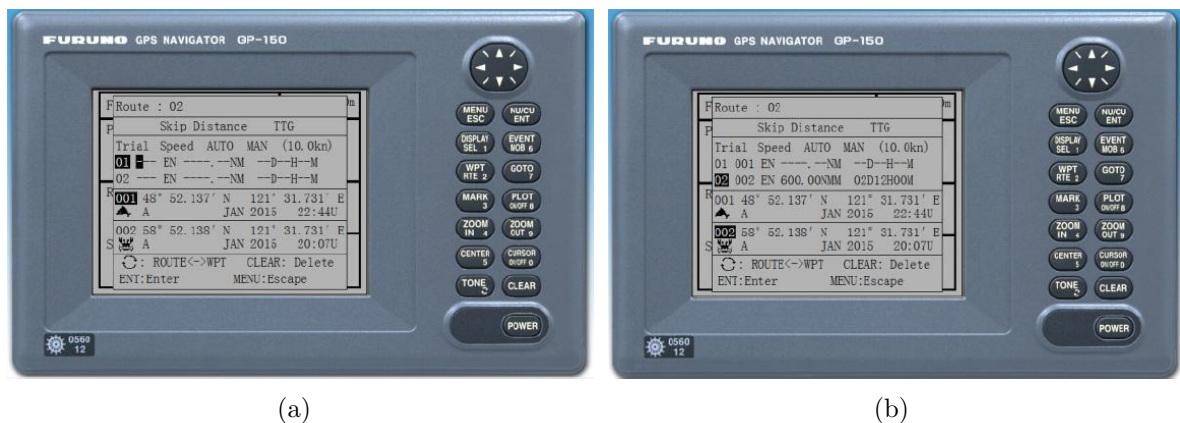

(a)   (b)

FIGURE 2. Route planning

2.3. **Transformation of coordinate systems.** WGS 84 is an Earth-centered, Earth-fixed terrestrial reference system and geodetic datum. WGS 84 is based on a consistent set of constants and model parameters that describe the Earth's size, shape, and gravity and geomagnetic fields. WGS 84 is the standard U.S. Department of Defense definition of a global reference system for geospatial information and is the reference system for the Global Positioning System (GPS). It is compatible with the International Terrestrial Reference System (ITRS).

The origin is the earth's center of mass being defined for the whole Earth including oceans and atmosphere. The Z-axis points to the direction of the IERS Reference Pole (IRP). The X-axis points to the intersection of the IERS Reference Meridian (IRM) and the plane passing through the origin and normal to the Z-axis. The Y-axis complies with right-handed, Earth-Centered Earth-Fixed (ECEF) orthogonal coordinate system.

The GPS receiver can use the different coordinate system. So the positions in different coordinates need to be converted.

Suppose the offset of origin in different coordinate systems is $(\Delta X, \Delta Y, \Delta Z)$, and the coordinate corrections can be calculated [8] by way of Formulas (6) and (7).

$$\Delta\varphi'' = \frac{1}{M\sin 1''}\left[\left(a\Delta e^2 + e^2\Delta a\right)\sin\varphi\cos\varphi + ae^2\Delta e^2\sin^3\varphi\cos\varphi \right. \tag{6}$$
$$\left. - \sin\varphi\cos\lambda\Delta X - \sin\varphi\sin\lambda\Delta Y + \cos\varphi\Delta Z\right]$$

$$\Delta\lambda'' = \frac{1}{N\cos\varphi\sin 1''}\left[\cos\lambda\Delta Y - \sin\lambda\Delta X\right] \tag{7}$$

where, φ is the latitude of original coordinate, and λ is the longitude of original coordinate, and M is the curvature radius of meridian of original coordinate, and N is the curvature radius of prime vertical of original coordinate.

$$M = \frac{a(1 - e^2)}{\left(1 - e^2\sin^2\varphi\right)^{3/2}} \tag{8}$$

$$N = \frac{a}{\left(1 - e^2\sin^2\varphi\right)^{1/2}} \tag{9}$$

$$\Delta a = a_{new} - a \tag{10}$$

$$\Delta e^2 = (2 - 2c)(c_{new} - c) \tag{11}$$

where, a_{new} is the major semi axis of ellipse of new coordinate, and a is the major semi axis of ellipse of original coordinate, and c_{new} is the oblateness of ellipse of new coordinate, and c is the oblateness of ellipse of original coordinate, and e is the eccentricity ratio of ellipse of original coordinate.

The latitude and longitude in the new original coordinate can be got by way of the following formula.

$$\begin{aligned}\varphi_{new} &= \varphi + \Delta\varphi'' \\ \lambda_{new} &= \lambda + \Delta\lambda''\end{aligned} \tag{12}$$

2.4. **Accessing technology of database.** The database is employed to manage the waypoints and routes. The function of accessing, saving, querying and deleting of waypoints and routes can be done by way of ADO accessing technology. The ADO accessing technology can be used to access different database, and the programming is simple, and the programming interface is flexible. Taking the setting of waypoints as an example, the flow chart of the ADO accessing technology is shown in Figure 3. The database operations of saving, querying and deleting are used in Figure 3.

The MARK of waypoints must be modified when the waypoint is created or modified. The code of different MARK is saved with the waypoint, so the related figure can be shown on the display through these codes. The MARK of the waypoint is displayed by way of bitmap technology. Through creating the compatible DC, selecting bitmap into the compatible DC and copying the bitmap from the compatible DC to the current DC, the figure of MARK can be displayed at last. Figure 4 demonstrates the modification of waypoints including latitude, longitude, mark, and comment. Figure 5 demonstrates the process of making a navigation route. The five waypoints of NO.001, NO.002, NO.003, NO.004 and NO.007 are selected into the route, then the waypoint of NO.004 is deleted, and the total trip and navigation time can be calculated again for the rest waypoints at last.
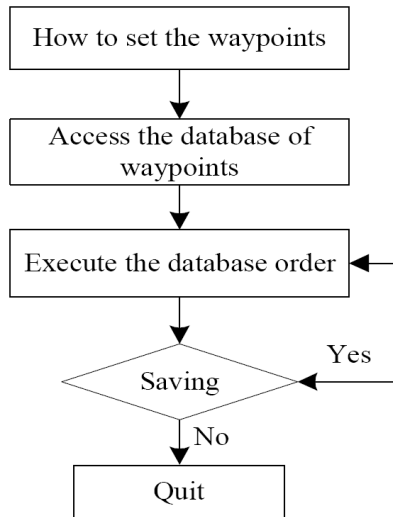
FIGURE 3. Flow chart of waypoint setting

(a)   (b)

FIGURE 4. Waypoint changing and saving

(a)   (b)

FIGURE 5. Waypoint deleting

3. **Simulation of Display Mode.** There are four different display modes (plotting mode, route mode, user mode, navigation mode) in the FURUNO GP-150 GPS receiver. Information obtained in different display modes is various. Figure 6 shows the user display mode. The information shown on the screen can be selected by the officer on watch. The information includes date and time, position in latitude and longitude, ship's time,

bearing, range, etc. At the same time, next destination waypoint and current destination waypoint can be gained in the user display mode. Figure 7 shows the navigation display mode. The display mode which supplies the information of latitude, longitude, course over ground, speed over ground, velocity to destination, cross track error meter, cross track error indication is used for ship's navigation. ETA (Estimated Time of Arrival) and TTG (Time To Go) can be calculated.

FIGURE 6. User display mode

FIGURE 7. Navigation display mode

4. **Conclusions.** The simulator of FURUNO GP-150 navigator is developed by way of Microsoft Visual Studio 2010. Through performing research on Great Circle Track, the problem of calculating an uncertain waypoint by way of a certain waypoint is settled down. In the calculation of navigation route, the parameters related to the voyage between different waypoints can be got. Through analyzing the difference between the WGS 84 coordination and others, the problem on transformation of ship's position is solved. The waypoints and routes are managed with the database by way of the ADO accessing technology. The operation of simulator is the same to the real equipment and the user interface is friendly. It can replace real navigator to be used in the training. The developing technology and experience would be very useful for the simulation of other navigation instruments.

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