Research on Automatic Positioning based on Radar System

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Abstract. The purpose of this study is to provide a fast, continuous and accurate alternative positioning method for coastal ships under the condition of abnormal satellite positioning; On the basis of the traditional artificial radar location, a position information based on the reference target is developed, the target tracking function of radar is applied, the distance and azimuth data of the reference target to the ship are automatically collected, and the automatic radar location method of the ship's position is determined by means of the mathematical model of track; Through the experimental calculation and the real ship data, it is proved that the radar location with high precision can be realized under the condition that the reference target position information is obtained accurately.

1. Introduction
In the course of ship navigation, accurate and reliable ship positioning and navigation is the main measure to ensure the safety of ship navigation, but also an important means to reduce the operating cost of ships [1]. With the development of electronic information technology, radio positioning technology plays a dominant role in ship positioning and navigation, in which GPS positioning as the representative of satellite navigation and positioning technology, with its high precision, wide coverage, easy to use and so on, is currently the first choice of ship positioning[2]～[5]. However, GPS positioning depends on receiving external (border) satellite signals, which are susceptible to interference in certain waters at certain times, affecting the reliability of their use [6] [7].

Inshore navigation, especially within 10mile of the coast, radar can provide high positioning accuracy, is the pilot's alternative positioning equipment, in the satellite positioning equipment in the event of anomalies can provide ship positioning[8]. The traditional radar positioning is through the pilot to compare the chart and radar image, choose the appropriate positioning target, measure the distance or position of the target, draw the corresponding target to the ship's distance or azimuth position line, two or more position line intersection is the ship's position[9][10].

In view of the limitations of manual radar positioning operation, large positioning error, and difficulty in providing continuous positioning, this study [11], based on the location information of the reference subject, uses the target tracking function of the radar, automatically obtains the distance and orientation data of the reference target to the ship, and calculates the latitude and longitude data of the ship, so as to realize the automatic radar positioning function. It provides a fast, continuous and accurate radar positioning method for coastal navigation vessels.
2. Ship position calculation mathematical model

It is known that the latitude and longitude of a reference object A is \((\lambda_A, \varphi_A)\), and the orientation of the object A relative to the ship is \(\theta\) on the radar, and the distance is \(R\). In order to calculate the latitude and longitude data of the ship, the object distance \(R\) is along the warp.

The latitude is decomposed into \(S_Y = R\cos\theta\) and \(S_X = R\sin\theta\), as shown in Fig 1.

\[
\begin{align*}
\text{Figure 1. Schematic diagram of the reference object plane decomposition}
\end{align*}
\]

Suppose that A moves along the meridian by an infinitesimal distance to reach \(A'\), and the latitude increases by \(d\varphi\). Let the radius of curvature of the position where the reference object A is located is \(M\) (as shown in Fig. 2), then the differential arc length \(AA'\) corresponding to the line is:

\[
\overline{AA'} = ds_m = M d\varphi
\]

\[
\text{Figure 2. Schematic diagram of meridian distance calculation}
\]

From the reference object A, it reaches any point B along the meridian, and its latitude is \(\varphi_B\). The warp length \(s_m\) from \(\varphi_A\) to \(\varphi_B\) can be calculated by integrating the formula (1), namely:

\[
s_m = \int_{\varphi_A}^{\varphi_B} M d\varphi
\]

Substituting the radius of curvature of the meridian circle \(M\), after finishing, it is obtained:

\[
s_m = a_e(1 - e^2)\alpha(\varphi_B - \varphi_A) - \frac{\beta}{2}(\sin 2\varphi_B - \sin 2\varphi_A) + \frac{\gamma}{4}(\sin 4\varphi_B - \sin 4\varphi_A) - \frac{\delta}{6}(\sin 6\varphi_B - \sin 6\varphi_A)
\]
Among them, \( a_e \) is the long radius of the earth ellipsoid, and \( e_1 \) is the first eccentricity of the meridional ellipse. The calculation methods and values of the other parameters are as follows:

\[
\alpha = 1 + \frac{3}{4} e_1^2 + \frac{45}{64} e_1^4 + \frac{175}{256} e_1^6 + \frac{11025}{16384} e_1^8 + \ldots
\]
\[
\beta = \frac{3}{4} e_1^2 + \frac{15}{16} e_1^4 + \frac{512}{2205} e_1^6 + \frac{2048}{4096} e_1^8 + \ldots
\]
\[
\gamma = \frac{15}{64} e_1^4 + \frac{105}{256} e_1^6 + \frac{4096}{315} e_1^8 + \ldots
\]
\[
\delta = \frac{35}{512} e_1^6 + \frac{315}{2048} e_1^8 + \ldots
\]

When the B point latitude \( \varphi_B \) is taken as:

\[
\varphi_B = \varphi_A \pm 1^\circ
\]

The corresponding arc length \( D_Y \) of the reference target A moving by 1° along the meridian circle can be calculated.

Therefore, the latitude difference \( \Delta \varphi \) of the ship to the reference point A is:

\[
\Delta \varphi = \frac{S_Y}{D_Y}
\]

The latitude \( \varphi_0 \) of the ship is:

\[
\varphi_0 = \varphi_A \pm \Delta \varphi
\]

In the same way, the longitude difference of the ship from the reference target can be calculated, and the distance \( S_n \) from the reference object A to the arbitrary point C along the latitude circle is:

\[
S_n = r(\lambda_C - \lambda_A) = N \cos \varphi_A (\lambda_C - \lambda_A)
\]

Where \( N \) is the radius of curvature of the circle.

\[
N = \frac{a_e}{(1 - e_1^2 \sin^2 \varphi_A)^{3/2}}
\]

Taking \( \lambda_C - \lambda_A = 1 \), using the formula X, the arc length \( D_X \) corresponding to the movement of the reference object A along the latitude circle by 1° can be obtained. The longitude difference \( \Delta \lambda \) between the ship and the reference object A is:

\[
\Delta \lambda = \frac{S_X}{D_X}
\]

The longitude \( \lambda_0 \) of the ship is:

\[
\lambda_0 = \lambda_A \pm \Delta \lambda
\]

3. Radar positioning model accuracy measurement

In order to verify the positioning accuracy of the aforementioned mathematical model of ship position estimation, by setting the reference targets of different distances and azimuths on the radar equipment, extracting the position data of the reference object, the distance and the bearing data with respect to the ship, and substituting the mathematical model of the ship position calculation, respectively The ship's
position is compared with the actual position of the ship, and the accuracy of the radar positioning model is measured.

Taking the 3 nm range as an example, the reference objects are set at 1 nm, 1.5 nm, 2 nm, 2.5 nm, and 3 nm where the relative orientation of the ship is 45°, 135°, 225°, 315°, and the reference object position is set as shown in Fig. 3. As shown, the corresponding error between the estimated ship position and the actual ship position is shown in Fig. 4.

Further experiments were carried out under different radar ranges, and reference objects of different distances and azimuths were set to obtain errors between multiple sets of model estimated ship positions and real ship positions. The results are shown in Fig. 5.
From the above calculation results, we can know: (1) The farther the reference object is from the ship and the larger the range setting, the larger the ship position error is calculated by the mathematical model of the ship position calculation; (2) Within the radar measurable range, the mathematical model of the ship's position calculation is highly accurate. When the reference object distance is less than 32nm, the positioning error is kept below 45m, which meets the accuracy requirements of emergency positioning under complex sea conditions.

4. Real ship verification

In the case of real-time ship collection of reference object information, this study uses two methods to obtain ship position information: (1) Setting the cursor position, when it coincides with the reference object center, the position information of the cursor is the reference object position information; (2) Using the radar to capture the reference object, you can get its position information. In this study, by collecting the surrounding object information of the "Chang Hang Fu Hai" ship, the ship position is calculated and compared with the GPS position, and the model positioning error is measured. When the ship is sailing in the river, the small-range and close-distance reference objects are selected. Taking the Yangtze River navigation as an example, Jiangsu Nantong Longclaw is selected as the reference object. The object position and positioning error results are shown in Fig. 6.
When the ship is sailing on the sea, a large-range and long-distance reference object is selected, and DaGong Island is used as a reference object. The calculation error results are shown in Fig. 7.

![Figure 7](image)

**Figure 7.** Location and accuracy of coastal positioning reference object verification results

The result proves that the positioning model has higher precision in practical applications and meets the needs of practical applications. Since the cursor position data is derived from the information of the radar system device itself, and the captured object position belongs to the real data, although the former has higher precision, the latter has greater application value. Moreover, the radar has a small range and a reference object distance, and the positioning accuracy is higher.

In addition, when the ship sails at sea, the positioning accuracy of the reference object crosses the ship after it crosses the ship. According to the analysis, since the radar electromagnetic wave is blocked by the island topography, only the part of the reference object can be detected. Therefore, the reference object radar is returned. The position of the center of the shape of the wave before and after it crosses the ship is inconsistent, thus causing a large error. In order to reduce the error caused by the change of the echo center coordinate, the coordinate of the reference object is calculated according to the reference object topography. After correction, the positioning accuracy check result is shown in Fig. 7.

5. **Automatic radar positioning system implementation**

Through GPS, radar, electronic compass and other equipment output information, design software to achieve automatic radar positioning when GPS signals are missing. Software function implementation is divided into two stages: reference object information acquisition and radar positioning. When the GPS signal input is normal, the ship is positioned by GPS. The system is in the stage of reference object information collection; when the system detects the GPS signal input abnormality, it enters the radar positioning stage to calculate the ship's position. (1) Information synthesis When the GPS signal is normally connected, the electronic compass signal and the GPS signal are input into the radar device, and the radar and GPS original code information are collected in real time. (2) Obtain the reference object latitude and longitude After decoding, the ship's position is obtained, and the radar automatically captures the surrounding stationary object as a reference object to obtain the target distance and position, thereby obtaining the reference object latitude and longitude. (3) Calculation of the ship's position When the system detects the abnormality of the GPS signal input, the radar obtains the distance orientation of the reference object relative to the ship, and combines the reference object latitude and longitude measured when the GPS works normally, and uses the radar positioning model to calculate the ship's position. The system hardware assembly and program working interface are shown in Fig. 8.
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