A TERRAIN-AIDED NAVIGATION ALGORITHM FOR MARINE SYSTEMS BASED ON CORRELATION METHOD

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ABSTRACT: In recent years, integration of inertial navigation system and a GNSS based method (especially Global Positioning System) is the most common way for navigation used by vessels. Although GNSS based positioning methods are accurate and convenient, complete reliance on these systems is not logical because the blockage of GNSS signal is probable. After loosing GNSS signal, INS plays an essential role in the process of navigation. In this way, the accuracy of positioning is diminished during the time. The reason of accuracy reduction is the inherent sensor errors that exhibit considerable long-term growth. So applying alternative methods like aided navigation systems is a must in places where the vessel maneuvers in the shallow water and near the coastlines. One of the most common aided navigation methods, terrain aided navigation, guarantees and improves the accuracy of positioning based on altitude measurements provided by auxiliary sensor. In this method, while the accuracy of positioning by INS get worse than acceptable limit, the vessel position is corrected by a correlation function which makes a connection between digital terrain models and altitude observations. In this method, kalman filter is used to reduce the INS errors, also to establish a criterion for position accuracy. Simulation result shows the great performance of proposed method.

1. Introduction

Modern navigation methods are often based on an interaction between position estimating system and an inertial navigation system as a basic position estimator(Bergman, Ljung et al. 1999). The inertial navigation system is a self-contained system which incorporates three orthogonal accelerometers and three orthogonal gyroscopes. They measure three linear accelerations and three angular rates. To determine position, velocity and attitude information, a set of mathematical transformation and integration with respect to time are applied(Semeniuk and Noureldin 2006). The measurements of INS[1] are accurate but, unfortunately, it cannot operate on a stand-alone basis, because the accuracy of INS measurements diminish with the time due to the inherent sensor errors that exhibit considerable long-term growth(Farrell and Barth 1999). Nowadays, to solve this problem, most of the navigation methods use GPS[2] to update the INS position and its error. The GPS based methods are relying on satellite signal broadcast to the vessel, so in critical situation, complete reliance on this system is not logical. So, applying alternative methods which don't rely on external infrastructure is necessary. Terrain aided navigation is an independent positioning method which the position of the vessel is corrected by comparing information gathered by an altimetry sensor with digital terrain maps(DTM). In

[1] Inertial Navigation System

[2] Global Positioning System

most cases, Kalman filter is used to integrate TAN[3] and INS to increase accuracy and reliability.

2. Marine navigation

In critical situations, while satellite based methods of navigations are not reliable, there must be an alternative method to estimate the true position of vessel. Many marine and underwater methods are based on fixed acoustic transponders that are installed into the vessel's work area. Other method in this group is based on tracking a body without introducing fixed point through the use of ultra-short baseline technolog(Whitcomb, Yoerger et al. 2004). Implementation of these methods is costly and time consuming and also their performance can vary with conditions within the water column in which the vessel is operating(Williams and Mahon 2006).

Using terrain information is another way to estimate the position of the vessels or underwater submarines and AUV[4]s. In this method, accurate position of vehicle is obtained by corresponding between pre-stored terrain maps and altimetry information gathered by auxiliary sensor. Appropriate performance in all weather condition is the most important advantage of this method. But, the most considerable issue of terrain based navigation is inefficiency in environment that has smooth terrain(Bergman, Ljung et al. 1999).

In recent years, terrain reference navigation has been prospered by progressing the modern sensor like multibeam echo sounder. Multibeam echo sounder is one of the most advanced sonar systems in which depth of seabed is determined by measuring the time interval between the emitted and received sound waves. Recent development in this sensor extends its capabilities to provide 100% bottom coverage. Consequently, it is expected that data provided by this sensor presents a considerable correction for vehicle position.

3. Terrain aided navigation

The accumulative characteristic of positioning error in INS decreases accuracy of navigation. So, In TAN, this problem is solved by using a non-linear estimator through which a connection will be established between pre stored referenced maps and elevation observations.

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[3] Terrain Aided Navigation

[4] Automatic underwater vehicle

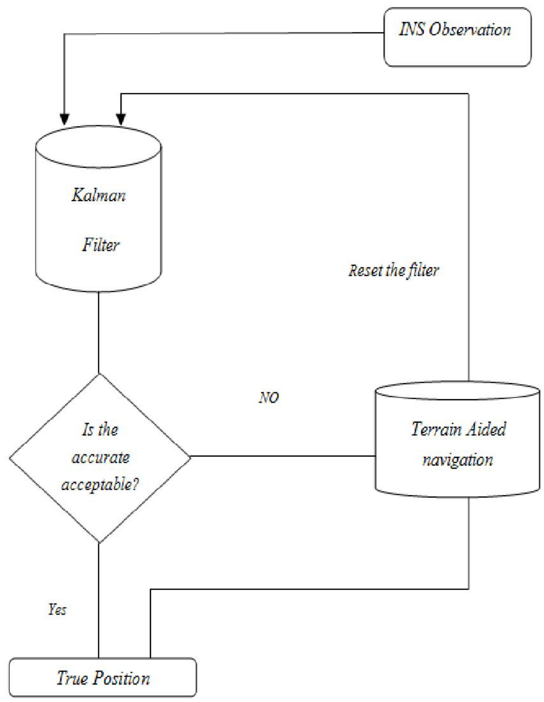

Figure 1 :terrain aided navigation

After blocking GPS signal, as shown in figure 1, INS plays an essential role in the process of navigation. The INS gives the relative movement, distance and heading, between two measurements.

$X_{t+1} = X_t + V_t$ (1)

In (1), this movement is modeled by a stochastic process Vt in the state transition equation. By passing the time, the accuracy of positioning with this equation is diminished. The reason of accuracy reduction is the inherent sensor errors that exhibit considerable long-term growth(Grewal and Andrews 2008) Whenever accuracy of positioning gets worse than the satisfied condition, more accurate position can be provided by TAN. Therefore, the main part of TAN is the non linear estimator which suggests true position and also restarts the Kalman filter. The ways that this estimation is established are varied.

In (Clem 1977), The Terrain Contour Matching (TERCOM) system which provides a positional fix by correlating a terrain profile with a stored topographical map and taking the location of the best match to be the position of the vehicle was developed. To solve the problem of TAN, other methods like SITAN [5] (Hostetler and Andreas 1983), TERPROM[6](Davies 1995),VATAN[7](Enns and Morrell 1995) ,PTAN[8](Campbell 2006) were developed but because of their inadequate performance, most of them are inapplicable. In this paper, this problem is solved by correlation method.

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[5] Sandia Inertial Terrain Aided Navigation

[6] Terrain Profile Matching

[7]Viterbi Algorithm Terrain Aided Navigation

[8] Precision Terrain Aided Navigation

4. Correlation method

In this step, the position of the vessel is corrected by establishing a connection between DTM and altitude observation. These observations are gathered by mutli beam echosounder, in this way, they are scattered across track of vessel position.(figure2)

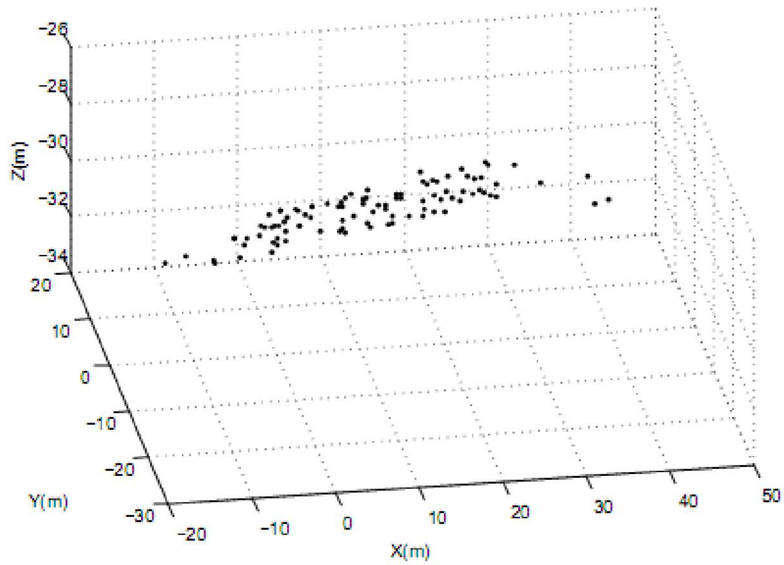

Figure 2 : altitude observations by multi beam echosounder

In this paper, the correlation function is implemented to correct the position of the vessel. This method is one of the most common ways to temple matching. In this method, finding the correct position is based on equation 1.

$$\gamma = \frac{\sum F(x,y) * f(x,y)}{\sqrt{(\sum F(x,y))^2 * (\sum f(x,y))^2}} \qquad (1)$$

In this equation,(x,y) is the horizontal position of the vessel and $f(x,y)$ is the depth related to (x,y) masured by multi beam echo sounder and $F(x,y)$ is the depth estimated by DTM. We are looking for a position in model space which maximizes γ.the calculation process of correlation is shown in figure 2.

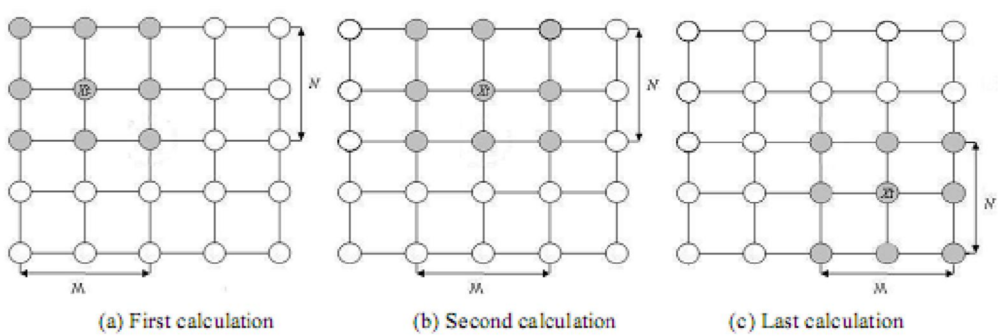

Figure 3: calculation of correlation(Jianchun, Rongchun et al. 2007)

5. Simulation

In this section, the performance of proposed method for terrain aided navigation is presented. The simulated movement has been performed over real terrain data. To ensure that proposed method performs correctly, the data set includes rough terrain.

First, to make certain about the precision of proposed model, the efficiency of position correction for one point is measured.

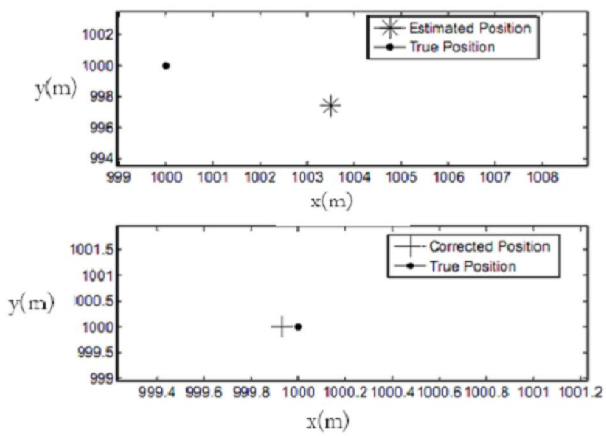

Figure 4: correction of position

As it is shown in figure 4, the true position of vessel is satisfactorily estimated by proposed method. In next step, for testing the accuracy of the proposed method, we try to compare terrain aided navigation estimated position and true position of the vessel in a true trajectory (figure 5).

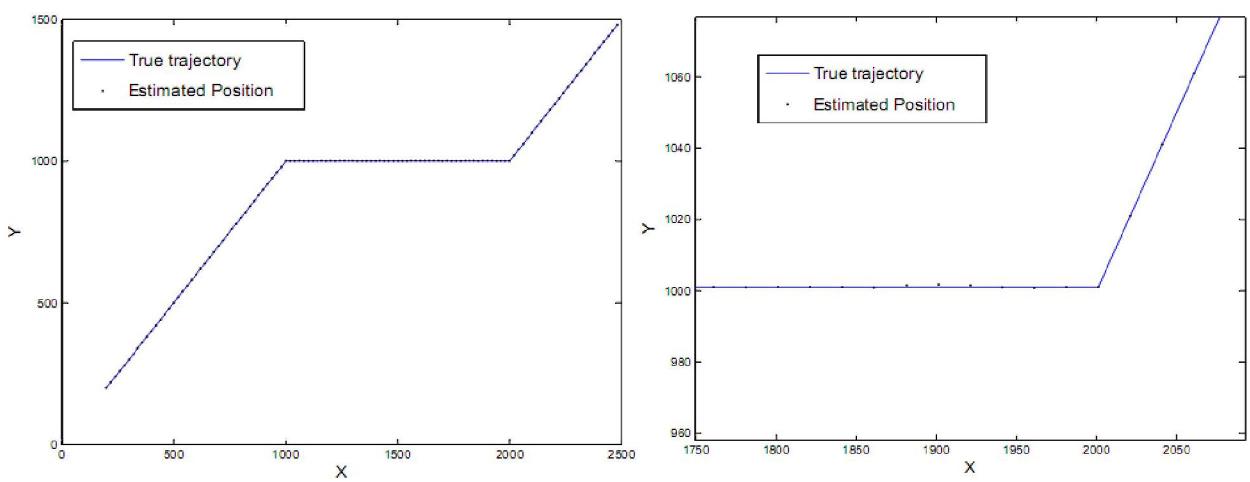

Figure 5: comparison between true trajectory and estimated position by terrain aided navigation method

The position of the vessel is estimated with high accuracy along the trajectory (figure 5). As it mentioned in (Bergman,et al. 1999), the only parameter that has effect on the accuracy of positioning is the rate of terrain roughness.

6. Conclusion

In spite of pervasive of satellite based navigation method, in critical situation, applying alternative method is rational. Terrain aided navigation is one of the most widely used method, in this method, the true position of the vessel is corrected by used a non linear estimator. In this paper, this problem is solved by correlation function which significantly reduces the amount of calculations but still inefficiency in smooth terrain is the main disadvantages of terrain aided navigation.

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