Ocean Engineering 108 (2015) 33–45

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Performance enhancement of INS/CNS integration navigation system based on particle swarm optimization back propagation neural network

Qiuying Wang [a], Yibing Li [a], Ming Diao [a,*], Wei Gao [b], Zhao Qi [b]

[a] College of Information and Communication Engineering, Harbin Engineering University, Harbin, China
[b] College of Electrical Engineering and Automation, Harbin Institute University, Harbin, China

ARTICLE INFO

Article history:
Received 31 March 2015
Accepted 30 July 2015
Available online 24 August 2015

Keywords:
Star Sensor
Inertial navigation
Integrated navigation
Particle swarm optimization
BP neural network

ABSTRACT

For the surface ship integrated navigation system of INS/CNS, the Star Sensor may invalidity due to the cloud weather, which leads to the integrated system cannot work anymore. To resolve the problem, an INS/CNS integrated navigation method based on particle swarm optimization back propagation neural network (PSO BPNN) is proposed in this paper. During the effective Star Sensor navigation process, the INS positioning error can be obtained and used for training PSO BPNN; when the Star Sensor is in invalid state, the already trained BPNN is used for forecasting the INS positioning error. The effectiveness of this approach was demonstrates by simulation and experimental study. The results showed that the INS/CNS integrated navigation method based on PSO BPNN can effectively estimate and compensate the INS navigation error under the star senor invalid state.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

There are three main types of navigation techniques for surface ship: satellite navigation, inertial navigation and celestial navigation (Weston and Titterton, 2000). The satellite navigation does not belong to the autonomous navigation, and it is very vulnerable to failure or to be deceived in the electronic environment of the modern battlefield. Therefore, the navigation method for the surface ship without the satellite navigation becomes a hot topic in recent years.

Inertial Navigation System (INS) is a full-autonomous navigation technique, and the velocity, position and attitude of the vehicle can be obtained continuously by the measurements of angular motion and line motion (Titterton and Weston, 2004; Broxmeyer, 1962). As INS calculating process does not depend on any external devices and cannot be influenced by environment factors, it is widely used in surface ship as the main navigation system. However, limited by the INS navigation calculation method, the navigation information provided by INS only keeps high precision in short time. The INS navigation errors will accumulate over time to divergence in long duration (Grenon et al., 2001; McEwen et al., 2005; Syed et al., 2008). To resolve the problem, external reference information is often introduced to reset and correct the divergent errors of INS, which forms the integrated navigation systems.

One way of mitigating INS growth and bounding errors is to update the initial system periodically or continuously with an external aiding. Therefore when an external aiding is available aboard the navigating vehicle, the navigation accuracy can be greatly improved through the external measurements. Global Navigation Satellite System (GNSS) is a prevalent choice for SINS augmentation. Kwang et al. (2009) proposed an adaptive two-stage extended Kalman filter (ATEKF) using an adaptive fading EKF, and the ATEKF is applied to the INS–GPS (inertial navigation system-Global Positioning System) loosely coupled system. The proposed ATEKF estimated the unknown bias effectively although the information about the random bias was unknown. Jiancheng and Xiaolin (2010) proposed a modified iterated extended Kalman filter (IEKF) and an INS/GPS integration system is implemented and applied to synthetic aperture radar (SAR) motion compensation. Myeong. (2012) proposed an adaptive filter that can estimate measurement noise variance in the INS/GPS integration system using the residual of the measurement. The INS navigation error are corrected periodically or continuously by the integrated navigation method mentioned above, but these methods cannot work under the condition of the GPS signal outage, especially for attack and deception jamming in the electronic environment modern war. Therefore, the navigation technology without GNSS is a research focus in the navigation filed. Qin et al. (2012) proposed a self-constructive ANFIS (SCANFIS) combined with the extended Kalman filter (EKF) for MEMS-INS errors modeling and predicting to improve the positioning accuracy when a GPS signal is blocked. Noureldin et al. (2009) proposes the approach of enhancing the positioning accuracy during GPS outages by nonlinear modeling of INS position errors at the information fusion level using neuro-fuzzy

* Corresponding author. Tel./fax: +86 045182589395.
E-mail address: diaomingwqy@163.com (M. Diao).

http://dx.doi.org/10.1016/j.oceaneng.2015.07.062
0029-8018/© 2015 Elsevier Ltd. All rights reserved.

(NF) modules, which are augmented in the Kalman filtering INS/GPS integration. The integrated navigation methods above are designed for the GPS signal outage for a short time. But these methods cannot work when the GPS signal is blocked for long time.

Celestial Navigation System (CNS), which provides the accurate attitude and position information, is an autonomous navigation system. Star Sensor is the most cutting-edge field of CNS (Roelof and Van, 1994). And due to the fast development of the Star Sensor technology, it greatly promotes the development of CNS technology and gradually expands its range of applications from aviation and aerospace to marine applications. The biggest advantages of such systems are the high navigation accuracy, immunity to electromagnetic interference, and no navigation error accumulation over time such as INS. In theory, the attitude accuracy of the Star Sensor can reach several arc seconds, and the positioning accuracy can be better than 10 m (Shu et al., 2010; Jie et al., 2009). Therefore, the navigation information provided by the Star Sensor can be used as the reference information to correct the divergent errors of INS.

INS/CNS integrated navigation methods have been widely used and studied for ballistic missiles, airplanes and spacecraft (Qu et al., 2010; Rad et al., 2014; Xiao et al., 2010). These methods mainly focus on eliminating the accumulated errors of the INS for a moving object by using CNS output. Weiewn et al. (2013) proposed a new autonomous SINS initial alignment method assisted by celestial observations for lunar explorer, which uses star observation to help SINS estimate its attitude, gyroscope drifts and accelerometer biases. Farid and Fang (2005) proposed an analytical technique for computing and correcting the errors mounted up over a period of time due to unknown constant biases and misalignments by celestial observations. All of the coupled navigation methods mentioned above are used for the aerospace applications of the Star Sensor, and there is no deeply discussion that the Star Sensor is applied in surface ships. Shuai and Anguo, 2014 conducted research in the technologies of Star Sensor for marine: Based on the analysis of various environmental factors that influence the marine Star Sensor detection sensitivity, corresponding suggestions were proposed on the design and development of the marine Star Sensor. Although deep researches of marine Star Sensor were conducted above, there are no studies on the changes of stargazing conditions, which influence the INS/Star Sensor integrated navigation system.

Stars are used as the beacon of the Star Sensor: the camera installed in the Star Sensor takes photographs looking towards the sky, and the navigation information is obtained by comparing the photographs with the guide star catalog, which was downloaded in the Star Sensor. However, when the Star Sensor is applied to the surface ships, the navigation process is easy to be affected by weather and other factors (such as clouds). For example, the number of stars, which is used for calculating the navigation information of the Star Sensor, is reduced under the cloud weather. Hence, the navigation information provided by the Star Sensor cannot be obtained accurately, which lead to failure of the Star Sensor navigation. In this case, the integrated navigation process based on INS/CNS cannot work.

To solve these problems, INS/CNS integrated navigation method based on particle swarm optimization back propagation neural network (PSO BPNN) (Li et al., 2013; Boo., 2007) is proposed in this paper. In this method, the navigation information from the INS/Star Sensor integrated system are used to train BPNN during the effective navigation process of the Star Sensor; when Star Sensor momently fails to navigate, trained BPNN is used to predict the positioning error of INS. And the prediction results (INS position error) are used as the observations for Kalman filter to accomplish the integrated navigation process. In addition, in order to optimize the BPNN, particle swarm optimization (PSO) algorithm is adopted to optimally set all the weights and thresholds of the BPNN, so as to enhance the BPNN prediction effect and improve the navigation accuracy.

The paper is organized as follows. We provided the principle of INS/CNS Integration navigation system in Section 2, and under the cloud weather, the influence of the Star Sensor on the navigation accuracy are described in this section. The principle of PSO BPNN is discussed in Section 3. The INS/CNS integrated navigation method based on PSO BPNN is discussed in Section 4. Section 5 presents the simulation and experimental results, followed by a presentation of the conclusions from Section 4. Section 6 summarizes the whole paper.

2. INS/CNS integration navigation system

2.1. Principle of INS and system error model

Gyros and accelerometers are the main Inertial Measurement Units (IMU) of INS, and the vehicle's navigation information is obtained through the calculating process based on the IMU measurement. The principle of INS is shown in Fig. 1.where the scripts i is the Earth-Centered Inertial frame (ECI), n is the navigation frame (East-North-Up, ENU), e is the Earth-Centered Earth-Fixed frame (ECEF), and b is the body-fixed frame. $\mathbf{C}_b^n$ is a transformation matrix from b frame to n frame. $\mathbf{f}^b$ is the accelerometer output, $\boldsymbol{\omega}_{ib}^b$ is the gyro output. $\boldsymbol{\omega}_{xy}^z$ $(x = i, e, n,\ y = e, n, b, z = n, b)$ is the rotation rate along z between x and y. $\mathbf{q}_{nb}$ is rotating quaternion between b and n.

Based on the principle of INS, the position, velocity, and attitude equations for strapdown INS are expressed in (1). For simplify the problem, the navigation information related with the altitude in the INS error equation is ignored because of the research background of this paper is USV. The current position, velocity, and attitude can be obtained by integrating these equations with the angular rate and the acceleration data from IMU in

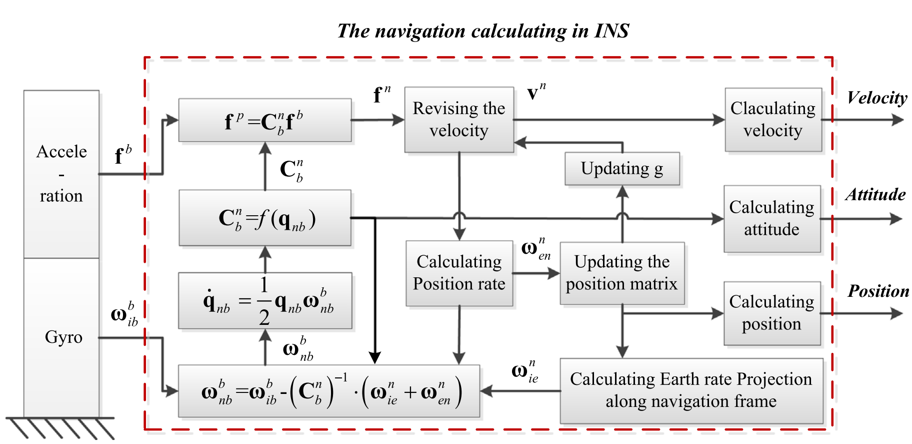

Fig. 1. Principle of INS.

Download English Version:

https://daneshyari.com/en/article/8065400

Download Persian Version:

https://daneshyari.com/article/8065400

Daneshyari.com