Analysis Method of the Terrain Navigable Performance Based on Isotropy Parameter

Zhe Rao[1,a], Jingyuan Zhang[1,b], Hui Liu[2,c] and Wei Feng[1,d]

[1]Department of Weaponry Engineering, Naval University of Engineering, Wuhan 430033, China

[2]Department of Science Research, Academy of Force Engineering, Beijing 100072, China

[a]icesnowaloe@126.com, [b]zhangjingyuan@sina.com, [c]liuhuibg@163.com, [d]476507122@qq.com

Keywords: Underwater terrain matching navigation; Isotropy parameter; terrain feature; navigation coefficient; navigable performance

Abstract. Because of using the distribution characteristics of submarine topography of correlation matching operation to estimate the current position, the navigation and positioning accuracy of the underwater terrain matching navigation depends largely on the terrain feature. In order to satisfy the requirements and improve the precision of navigation, the terrain matching area of navigability analysis is essential. The terrain navigability entropy analysis method with terrain information entropy of the alternative matching area, which is less difference even equal, is unable to determine the navigable performance of matching area. The terrain matching area navigation coefficient deriving from the combination of the isotropy parameter and terrain information entropy to measure the navigability of the matching area is proposed. The results show that the isotropic parameter is greater, the greater the navigation coefficient for the matching area with less different information entropy. Meanwhile, the matching area navigable performance is stronger.

Introduction

Navigation and positioning accuracy of underwater terrain matching aided navigation system not only depends on the matching algorithm, but also relates with the terrain navigable performance. Thus, how to choose the terrain matching area of terrain aided navigation is a key issue to improve the navigation accuracy. According to the entropy analysis method of terrain navigability for the alternative matching areas with less difference even equal entropy, it is unable to determine matching area navigable performance. The navigation coefficient is proposed based on terrain isotropic parameter and entropy. Furthermore, the navigable performance of matching area can be determined, and the reference for the selection of matching terrain is provided.

Navigation Coefficient of the Terrain Matching Area

Isotropy Parameter. According to the fractal theory [1], the terrain surface profile can be described by Weierstrass-Mandelbrot Function like this:

$$z(x,y)=g^{D-1}\sum_{n=n_1}^{\infty}\frac{\cos 2\pi\gamma^n i}{\gamma^{(2-D)n}} \tag{1}$$

$z(x,y)$ is the water depth of terrain surface profile; g is the characteristic scale coefficient; D is the fractal dimension; γ is the constant and more than 1; γ^n is the spatial frequency of the random process; n_1 is the minimum truncated frequency components of terrain surface profile.

The two order spectral moment of terrain surface profile on frequency bandwidth between ω_l and ω_h is

$$m_2=\int_{\omega_l}^{\omega_h}\omega^2 P(\omega)\,\mathrm{d}\omega=\frac{g^{2(D-1)}}{2\ln\gamma}\cdot\frac{1}{2(D-1)}\cdot\left[\omega_h^{2(D-1)}-\omega_l^{2(D-1)}\right] \tag{2}$$

$$P(\omega)=\frac{g^{2(D-1)}}{2\ln\gamma}\cdot\frac{1}{\omega^{5-2D}} \tag{3}$$

The surface spectral moment is

$$m_{r-s,s}=\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\omega_1^{r-s}\omega_2^{s}P\left(\omega_1,\omega_2\right)\mathrm{d}\omega_1\mathrm{d}\omega_2 \tag{4}$$

The two order spectrum moments of contour is

$$m_2(\theta)=m_{20}\cos^2\theta+2m_{11}\cos\theta\sin\theta+m_{02}\sin^2\theta \tag{5}$$

m_{20} and m_{02} are two order spectrum moments of surface and indicate the slope variance of two directions perpendicular to each other. m_{11} indicates the covariance of the two directions.

The slope variance of terrain contour reflects the amplitude distribution of the contour, and generally depends on the terrain contour direction. Therefore, we can use the two order spectral moments of terrain profile to characterize the surface anisotropy. If the ground surface is isotropic, $m_2(\theta)$ and θ are independent. The isotropic parameters can be expressed as

$$\eta=2\frac{\sqrt{\Delta_2}}{M_2}=\frac{2\sqrt{m_{20}m_{02}-m_{11}^2}}{m_{20}+m_{02}} \tag{6}$$

Navigation Coefficient. If the difference of terrain information entropy H_f is small even nothing, the selection criteria of terrain matching area only with the terrain information entropy is biased from the literature [2-5]. In this case, because of the difference in other parameters of topography, the terrain navigation performance is not the same. Consequently, an analysis method combined with terrain information entropy and isotropic parameter is proposed. The terrain matching navigation coefficient λ is the combination of terrain information entropy and isotropic parameter, then the navigation coefficient λ can be expressed as

$$\lambda=H_f+\eta \tag{7}$$

Particle Filter Algorithm

If the vehicle navigation adopted the depth setting mode, the system noise ω and the measurement noise ζ are zero mean and white Gauss noise, which are independent and identically distributed, and variances respectively are Q and R [6].

All of the particles $\chi_{k|k}^{i}\,(i=1,2\ldots N_s)$ in the particle swarm are carrying on the time updates by the system equations at the moment k. Thus,we can get the particle set $\{\chi_{k+1|k}^{i},\omega_{k+1|k}^{i}\}_{i=1}^{N_s}$ of predictable position $\hat{X}_{k+1|k}$ at the moment k+1. Using the depth information can update the particle weights as follows:

$$\omega_{k+1|k+1}^{i}=\omega_{k+1|k}^{i}\square p_{\zeta_k}\left(z_k-h_{k+1}^{i}\right) \tag{8}$$

and the weights are normalized as follows:

$$\omega_{k+1|k+1}^{i}=\frac{\omega_{k+1|k+1}^{i}}{\sum_{i=1}^{N_s}\omega_{k+1|k+1}^{i}} \tag{9}$$

So we can get the position and variance estimation of the vehicle at the time k+1:

$$\hat{X}_{k+1|k+1}=\sum_{i=1}^{N_s}\omega_{k+1|k+1}^{i}\square\chi_{k+1|k+1}^{i} \tag{10}$$

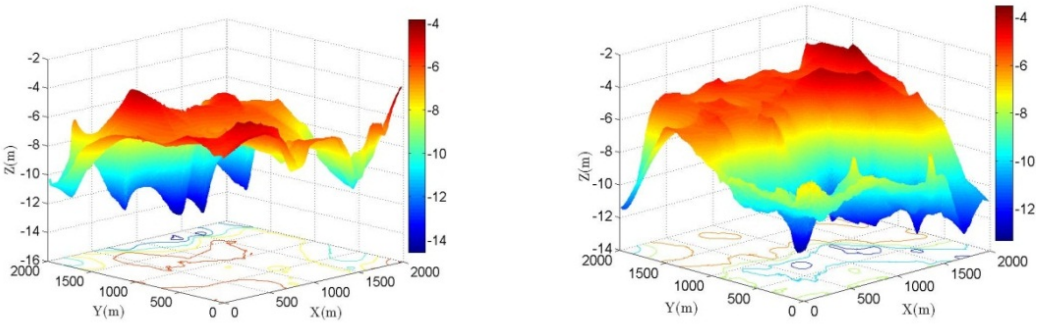
$$P_{k+1|k+1}=\sum_{i=1}^{N_s}\omega_{k+1|k+1}^{i}\left(\chi_{k+1|k+1}^{i}-\hat{X}_{k+1|k+1}\right)\left(\chi_{k+1|k+1}^{i}-\hat{X}_{k+1|k+1}\right)^T \tag{11}$$

$$N_{eff}=\frac{N_s}{1+Var(\omega_{k+1}^{i})}\approx\frac{1}{\sum_{i=1}^{N_s}(\omega_{k+1}^{i})^2} \tag{12}$$

If $N_{\text{eff}} \leqslant N_{\text{off}}$, we need resampling by a reasonable method. Otherwise, we should go to the time updates. The real-time estimation of the vehicle position and the matching path can be acquired by repeating the above recursive process.

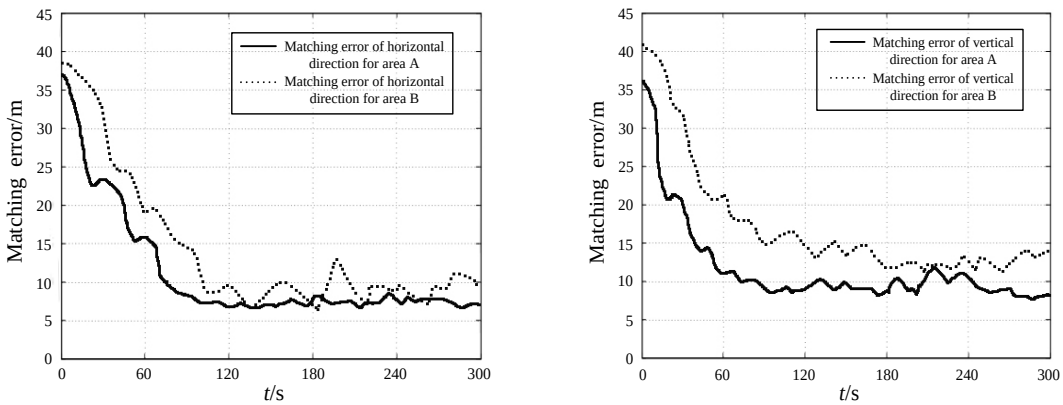
Simulation Examples

In order to verify the correctness of the proposed analysis method, and confirm the relationship with navigation coefficient and topography navigable performance, this paper selects terrain data of the lake test as the matching area A and B for simulation, and the three-dimensional terrain map as shown in figure 1. After calculation, the terrain information entropy of matching area A and area B are respectively 5.376 and 5.379, and the difference of entropy is less than 0.01. While the isotropic parameters of two areas are respectively η_A=0.483 and η_B= 0.239 .Thus, the matching navigation coefficients respectively are λ_A=5.859 and λ_B=5.618. Now, we simulate 1000 times through the Monte Carlo method by the matching operation of the particle filter algorithm on the same routes, so the results are shown in figure 2.



(a) Area A (b) Area B

Fig.1 Three-dimensional topographic map of terrain matching area



(a) Matching error of horizontal direction (b) Matching error of vertical direction

Fig.2 Curve of matching error

From the simulation results, if the terrain information entropy of two areas are almost equal. The isotropic parameters is greater, the greater navigation coefficient. So the navigable performance of matching area is stronger. Therefore, we should try to choose the matching terrain navigation area with the larger navigation coefficient to ensure that the matching error is smaller and improve the precision of navigation in the underwater terrain matching navigation.

Summary

The terrain navigation coefficient is proposed based on isotropic parameter, and this coefficient can measure the navigable performance of matching area. When the terrain information entropy size is very close, the isotropic parameter is greater, and the greater the navigation coefficient. The navigable performance of matching area is stronger. Therefore, the terrain navigation coefficient

can be used as a navigable evaluating criterion for navigable performance of terrain matching area, and provides theoretical basis for the path selection of underwater terrain matching navigation.

References

[1] Sayles R S, ThomasT R. Surface Topography as a Nonstationary Random Process[J]. Nature (271), 1978.
[2] Wang Tang, McClintock RL. Terrain Correlation Suitability[A]. Proceedings of the SPIE, 1994, vol 2220: pp. 50-58.
[3] Smith R, Cheesman P. On the Representation of Spatial Uncertainty. Int. J. Robot. Res 1987, 5, 56–68.
[4] Leonard J, Bennett A, Smith C. Autonomous Underwater Vehicle Navigation. IEEE J. Ocean. Eng 1998, 35: pp. 663–678.
[5] Williams S, Dissanayake G, Durrant-Whyte H. An Efficient Approach to the Simultaneous Localisation and Mapping Problem. Proceedings of the IEEE International Conference on Robotics and Automation (ICRA), Washington, DC, USA, 11–15 May 2002: pp. 406–411.
[6] Anonsen K, Hallingstad O. The Terrain Aided Underwater Navigation Using Point Mass and Particle Filters[J]. Position, Location and Navigation Symposium, 2006: pp. 1027-1035.