Magnetic–Gravity Gradient Inversion for Underwater Object Detection

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Abstract. A new nderwate object detection method ba ed on joint G a it -G adient and Magnetic-G adient In e ion algo ithm i p opo ed in thi pape . Magnetic g adient and g a it g adient anomalie ind ced b an nderwate object can be mea ed and in e ed to e timate the elati e change in di tance between nderwate object and nderwate ehicle. The weight lea t q a e e timation i int od ced to combine eq ation of magnetic g adient and g a it g adient in e ion. The efo e, the joint in e ion method get an optimal elati e po ition of nderwate object ing two kind of data. Sim lation e lt how that the p opo ed method i mo e efficient than the p e io Joint g a it g adient ten o in e ion and magnetic g adient ten o in e ion e pecti el .

Keywords: Magnetic g adient in e ion G a it g adient in e ion Unde wate object detection Weight lea t q a e e timation

1 Introduction

Undewate object detection i an a ea of e ea ch with b oad comme cial and milita application . How to detect nde wate abno mal object i till a majo challenge in nde wate na igation field nowada [1-2]. O e pa t decade , nde wate object detection tem ba ed on g a it g adient and magnetic anomal ha e been e ea ched widel [3-8]. In the field of nde wate object detection ba ed on g a it g adient ten o , Lin W ed g a it g adient in e ion method to detect abno mal object in nde wate en i onment [4]. F the mo e, in efe ence [5], joint g a it and g a it g adient in e ion i p e ented fo pa i e b face object detection. In efe ence [7], Z Yan p e ented a no el method fo nde wate object detection ba ed on the g a it g adient diffe ential and the g a it g adient diffe ential atio ca ed b the elati e motion between the AUV and the object. In the field of nde wate object detection ba ed on magnetic g adient ten o , Y H ang p opo ed a locali ation method combined with magnetic g adient ten o and d aft depth [8]. Hao an-ling p t fowa d an a ailable ol tion, whe e the geomagnetic anomal i in e ed a magnetic dipole ta get and the elati e po ition of ehicle i dete mined b magnetic magnit de and g adient of ta get [9].

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Afte con ide ing the in i ibilit eq i ement of AUV and the e i ting p oblem in ing g a it g adient and magnetic g adient fo detecting object , thi pape p o-po ed a no el and p actical ol tion to combine magnetic g adient In e ion and G a it G adient In e ion in an info mation f ion a , he e the o kind of data a e complementa to each othe and a optimal detection i calc lated b the eighted lea t q a e e timation.

Thi pape i o gani ed a follo . In Section 2, the joint g a it g adient and magnetic g adient in e ion algo ithm a e int od ced and anal ed, In Section 3, e pe iment and tim lation e lt a e di c ed. Concl ion a e mma i ed in Section 4.

2 Joint Gravity Gradient and Magnetic Gradient Inversion Method

2.1 Structure of Joint Geophysical Inversion Method

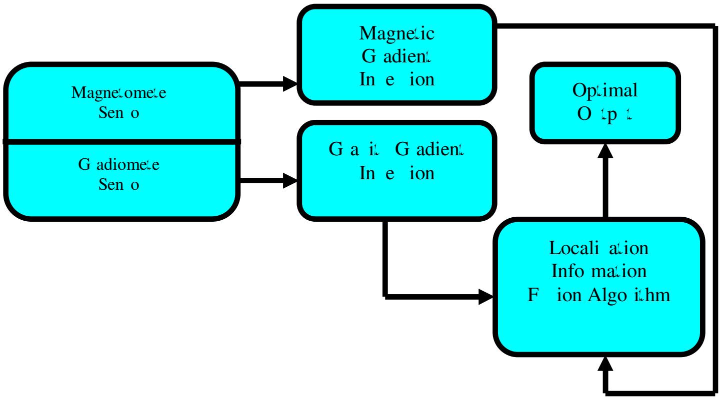

Fig. 1. Block diag am of Magnetic-G a it G adient In e ion fo Unde ate Object Detection

2.2 Introduction of Information Fusion Algorithm

In Fig1, afte calc lating the elati e di tance f om g a it g adient in e ion method and magnetic g adient in e ion method, hich a e denoted b b P_{gg} and P_{mg} e pecti el , the eighted lea t q a e e timation method in efe ence [4][5] i con- t cted to get an optimal elati e di tance bet een nde ate ehicle and nde a-te object. The optimal eq ation i ho n a follo :

$$\begin{cases} p_{Joint} = W_{gg} P_{gg} + W_{mg} P_{mg} \\ \begin{cases} \delta_T = \sqrt{\sum w_{ig}^2 \delta_{ig}^2} \\ \sum w_{ig} = 1 \\ 0 \le w_{ig} \le 1 \\ i = g,\ m \end{cases} \end{cases} \tag{1}$$

Where W_{gg} and W_{mg} are weights coming from gravity gradient inversion and magnetic gradient inversion. p_{Joint} is the optimal localization result from two Inversion methods, according to methods introduced in reference [8][9], the relative distance between an underwater object and underwater vehicle can be expressed as follows:

$$\begin{cases} \begin{cases} \frac{\partial B_x}{\partial X} = a = \frac{3\mu}{4\pi} \frac{x(3r^2-5x^2)m_x + y(3r^2-5x^2)m_y + z(3r^2-5x^2)m_z}{r^7} \\ \frac{\partial B_y}{\partial Y} = b = \frac{3\mu}{4\pi} \frac{x(3r^2-5y^2)m_x + y(3r^2-5y^2)m_y + z(3r^2-5y^2)m_z}{r^7} \\ c = -(a+b) \\ \frac{\partial B_y}{\partial X} = d = \frac{3\mu}{4\pi} \frac{y(3r^2-5x^2)m_x + x(3r^2-5x^2)m_y - 5xyzm_z}{r^7} \\ \frac{\partial B_z}{\partial Y} = e = \frac{3\mu}{4\pi} \frac{z(r^2-5y^2)m_y + y(r^2-5z^2)m_z - 5xyzm_x}{r^7} \\ \frac{\partial B_z}{\partial X} = f = \frac{3\mu}{4\pi} \frac{z(r^2-5x^2)m_x + x(r^2-5z^2)m_z - 5xyzm_y}{r^7} \end{cases} \\ \begin{cases} A_6k^6 + A_5k^5 + A_4k^4 + A_3k^3 + A_2k^2 + A_1k^1 + A_0 = 0 \\ A_6 = d^2(a+2b) - e^2(a-b) + 2def \\ A_5 = -2d\left[(a-b)(a+2b) + (d^2+e^2+f^2)\right] \\ A_4 = (a-b)^2(a+2b) + d^2(4a-7b) + (f^2-2e^2)(a-b) + 6edf \\ A_3 = -4d\left[(a-b)^2 + (d^2+e^2+f^2)\right] \\ A_2 = (a-b)^2(a+2b) + d^2(4b-7a)(2f^2-e^2)(a-b) + 6edf \\ A_1 = 2d\left[(a-b)(a+2b) - (d^2+e^2+f^2)\right] \\ A_0 = d^2(a+2b) + f^2(a-b) + 2edf \end{cases} \\ q = \frac{\left[d(k^2-1) - (a-b)k\right]}{(ek-f)(k^2+1)} \\ z = \frac{\pm 3}{\sqrt{\left[(ak+d)q+f\right]^2 + \left[(dk+b)q+e\right]^2 + \left[(fk+e)q+c\right]^2}} \\ x = kqz \\ y = qz \\ P_{mg} = \sqrt{x^2+y^2+z^2} \\ P_{gg} = R(x,y,z) = \sqrt[3]{\frac{GM}{\Gamma_{xx}(x,y,z)+\Gamma_{yy}(x,y,z)}\left(1 - \frac{3}{\left(\frac{\Gamma_{xy}(x,y,z)}{\Gamma_{yz}(x,y,z)}\right)^2 + \left(\frac{\Gamma_{xy}(x,y,z)}{\Gamma_{xz}(x,y,z)}\right)^2 + 1}\right)} \end{cases} \tag{2}$$

Where $\Gamma_{ij}(x,y,z)$ denote the gravity gradient values with coordinates x, y and z, respectively; $\theta(x,y,z)$ and $\varphi(x,y,z)$ stand for the relative orientation of an ndew ate object; $R(x,y,z)$ i a elati e di tance betw een the ndew ate ehicle and an ndew ate object that need to be detected; M i the ma of the object. G i the g a i-tation con tant [4-5]; In o de to get the al e A, it i nece a to mea ement mag-netic g adient (a, b, d, e, f), Acco ding to the method in efe ence [10], e en ingle-a i magnetomete config ation i a the imple t cheme of mea ing magnetic g adient ten o . Afte obtaining pa amete A, the i o de eq ation in Eq. (2) can be calc lated to get the al e of k, then, k i to calc late q. Finall , the ndew ate ehicle po ition pa amete (, ,) elati e to the ndew ate object can be calc lated b Eq. (2)

3 Stimulation Results

In o de to do a compa i onw ith the method in efe ence [4-5], a c be modelw a al o de igned fo the e timation of the change in di tance betw een an ndew ate ehicle and an ndew ate object. The ele ant pa amete a e li ted in Table 1. A ming po ition of ndew ate ehicle i fi ed and ndew ate object i mo ing. Ba ed on eq ation (2), afte getting the al e of g a it g adient and magnetic g adient ten-o , the elati e di tance betw een ndew ate ehicle and ndew ate object can be calc lated. Then eq ation (1) i to combine each g adient in e ion info mation b w eighted lea t q a e e timation method in efe ence [4][5].

Table 1. Pa amete of Undew ate Object Model

Model	Si e (m)
x di ection	20
y di ection	20
z di ection	20
Den it cont a t (kg/m3)	25
Act al ma of object(kg)	$6.624*10^4$
m_x	$10^6\ A \bullet m^2$
m_y	$2x10^5\ A \bullet m^2$
m_z	$10^5\ A \bullet m^2$

In thi pa t of the tim lation, a fi ed ndew ate ehicle and a mo ing ndew ate objectw e e a med. The den it di t ib tion and the i e of the objectw e e igno ed and the objectw a a med to be a pa ticle. While the objectw a mo ing, eq ence of a ing g a it g adient and magnetic g adient e pon e at the fi ed po ition of ndew ate ehicle co ld be mea ed im ltaneo l . Acco ding to Eq. (2), elati e po ition betw een ndew ate ehicle and mo ing object can be calc lated. Be ide , a con tant elati e e o of 12.33%w a added to magnetic g adient in e ion method, w hich mean that δ_{mg} in (1)w a eq al to 12.33%. When the elati e e o of g a it g adient (δ_{gg}) in (1) i 22.65%, he e, thew eight a e calc latedw ith (1) o that W_{gg}=0.219 and W_{mg}=0.781. The e timation e lt i how n in Fig. 2.

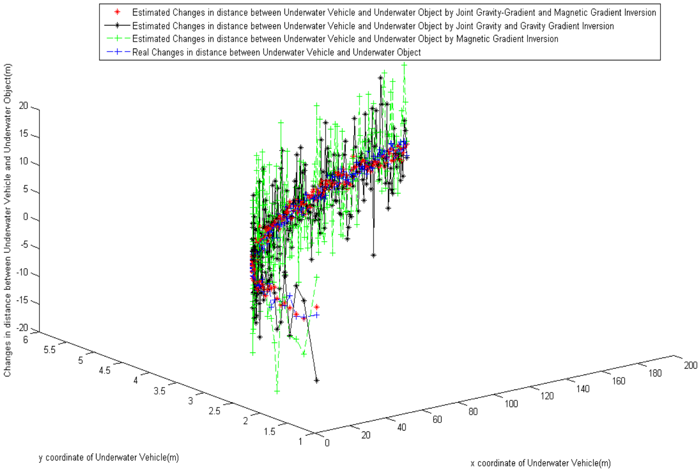

Fig. 2. A Comparison between actual changes in distance between Underwater Vehicle and Underwater object and estimated changes in distance between Underwater Vehicle and Underwater object based on Three Inversion method

In Fig.2, the actual change in distance between Underwater Vehicle and Underwater object is depicted with a blue line. The estimated change in distance between Underwater Vehicle and Underwater object by the proposed joint gravity gradient and magnetic gradient inversion method is denoted by red stars. The black stars are to denote the estimated changes in distance between Underwater Vehicle and Underwater object by Joint gravity and gravity gradient inversion. Finally, the green line is to illustrate the estimated changes in distance between Underwater Vehicle and Underwater object by magnetic gradient inversion. It is clearly seen that the estimated changes in distance between Underwater Vehicle and Underwater object by joint gravity gradient and magnetic gradient inversion method is in much better agreement with the actual changes in distance between Underwater Vehicle and Underwater object. In fact, the changes in distance between Underwater Vehicle and Underwater object is a good solution to reflect the relative position changes between Underwater Vehicle and Underwater object, the bias in estimated changes in distance between Underwater Vehicle and Underwater object comes from measurement outliers from magnetometers and gradiometers. The accuracy of each geophysical sensors has a great impact on the accuracy of Underwater object localization. In addition, the fluctuation of various terrain in Underwater environment has a great impact on the accuracy of Joint gravity and gravity gradient inversion method. Furthermore, electromagnetic disturbance in Underwater environment is another important factor which affects the accuracy of magnetic gradient inversion method. So, the joint gravity gradient and magnetic gradient inversion method is a good solution to eliminate such kind of negative influence on underwater object detection. The Fig.2 shows its effectiveness in underwater object detection.

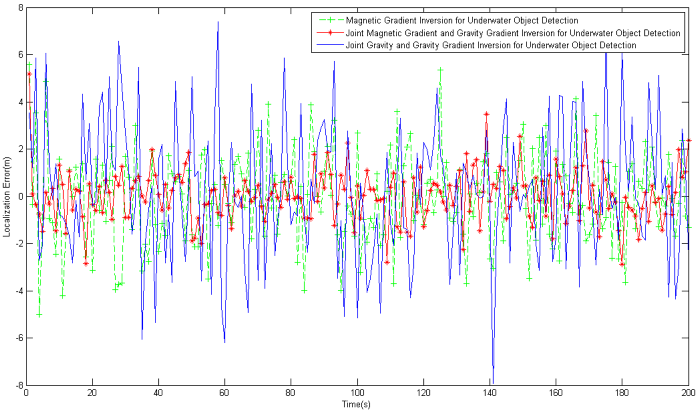

Fig. 3. E o Compa i on among th ee Undew ate Object Detection Method

In Fig.3, it i clea l to ee that Joint Magnetic G adient and G a it G adient In e ion method fo ndew ate object detection how the be t locali ation pe fo - mance among th ee method . In fact, g a it and g a it g adient i en iti e to the fl ct ation of a io te ain in the ndew ate en i onment, on the cont a , magnetic g adient i le affected b fl ct ation of ndew ate te ain and time- a di t bance . In thi wa , magnetic g adient i a good ol tion to combine with g a i- t g adient to eali e ndew ate object detection. In the f t e, it i nece a to pa mo e attention to imp o e the acc ac of magnetomete and g adiomete and de elop a bette ol tion to eali e data f ion method to f e g a it g adient and magnetic g adient info mation.

4 Conclusions

Undew ate Object detection method ba ed on joint g a it g adient and magnetic g adient in e ion ha been p opo ed. The weighted lea t q a e i int od ced to f e in e ion info mation f om g a it g adient in e ion and magnetic g adient in e ion e pecti el . With ch method, the change in di tance between ndew ate ehicle and an ndew ate object can be detected acc atel . Sim lation e lt how that the joint in e ion method i bette than mono-magnetic g adient in e ion method and joint g a it and g a it g adient in e ion method.

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