Academic Journal of Science and Technology
ISSN: 2771-3032 | Vol. 2, No. 1, 2022

Morphological Inversion Initial Model Position Estimation Method

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Abstract: The shape inversion method can clearly invert the three-dimensional attitude of the magnetic target, but the shape inversion needs to obtain the position information of the magnetic target to be measured. In order to better determine the magnetic target position information, a magnetic target morphology inversion method is proposed, which fuses the physical property inversion results. The center position of the magnetic target is calculated by the physical property inversion method; the initial model is set, the module growth selection function is established by using the L2 norm and the distance constraint function, and the optimal growth module in the morphological inversion process is selected; through continuous iterative update, the magnetic The 3D pose of the target. The position error calculated by this method is less than 10% of the actual value, and the inversion coincidence rate is greater than 80%. The results show that this method can effectively improve the accuracy of morphology inversion.

Keywords: Shape inversion, Physical property inversion, Magnetic targets, Magnetic gradient tensor, Prior.

1. Introduction

Magnetic target inversion is a method of inverting the magnetic parameters of the magnetic target through the magnetic survey data and using the obtained results to infer the information such as the shape and position of the magnetic target. Magnetic target inversion can intuitively provide magnetic target feature information, and it has very important application value in the fields of military reconnaissance, UXO removal and geological exploration [1]-[7].

The inversion methods of magnetic targets are mainly divided into physical property inversion and morphology inversion [8]. Physical property inversion is based on the magnetic field relationship between each point in the space to be measured and each point on the measurement surface, using the measurement data to calculate the magnetic parameters of each point in the space to be measured, and determining the three-dimensional attitude of the magnetic target based on the magnetic parameter value of each point [9]]-[11]. Because the number of points in the space to be measured is far more than the number of measurement points, the solution of physical property inversion is underdetermined, and the solution is not unique and unstable, resulting in unclear inversion results [12]. Morphological inversion is to continuously fit the corresponding geometric shape through the observation data under certain prior conditions, and simulate the three-dimensional shape of the magnetic target through the fitted geometry [13]-[14]. The morphology inversion method does not need to solve the inversion equation, avoids the ill-conditioned multi-solution problem in the inversion process, and can invert the attitude of the magnetic target more clearly, but its inversion accuracy depends on the prior information of the magnetic target to be measured [15].

In order to improve the accuracy of the morphological inversion method, this paper proposes a morphological inversion method of the magnetic target based on the physical property inversion results. The information sets the initial model, selects the appropriate module growth function to make the model grow and iterates, and finally obtains the three-dimensional pose of the magnetic target.

2. Method

The three-dimensional inversion process of the magnetic target in the morphological inversion method is as follows: first, use the magnetic gradient tensor data measured on the observation surface to calculate the center position of the magnetic target, and select the gridded area to be measured according to the calculated prior conditions. A cuboid mesh is used as the initial model in the morphological inversion, and it is given corresponding magnetic parameters; then a growing area is established around the initial model, and the growing area is composed of a cuboid that coincides with at least one face of the current model; According to certain judgment criteria, the optimal growth module is selected, and the current model is iterated to realize the construction of the inversion model; when the iteration termination condition is reached, the model stops iterating, and the three-dimensional pose of the magnetic target is obtained.

2.1. Morphological Inversion Prior Parameter Calculation

2.1.1. Parameter Calculation Based on Physical Property Inversion

Physical property inversion is to grid the space to be inverted, and establish a nonlinear equation between each grid and measurement points, and then solve the physical parameters of each grid. The generated magnetic outliers are equal to the measured values, that is, the cumulative value of the magnetic outliers generated by each grid in the space to be inverted for a certain measurement point should be equal to the measured value, which can be expressed as:

$$G_i = \sum_{j=1}^{N} A_{ij} m_j \tag{1}$$

In the formula, G_i is the measurement value of the i-th (where i=1,…,N,N is the number of measurement points); m_j is the j-th (j=1,…,M, M is the grid number) net The physical parameters of the grid, this paper is the magnetization; A_{ij} is the kernel function of the i-th measurement point corresponding to the j-th grid. Write equation (1) in matrix form:

$$\boldsymbol{G} = \boldsymbol{A} \cdot \boldsymbol{m} (M \gg n) \tag{2}$$

In the formula, $\boldsymbol{G}$ is the measurement point data matrix, $\boldsymbol{A}$ is the kernel function matrix, and $\boldsymbol{m}$ is the magnetic target physical property parameter matrix.

It can be seen from formula (2) that the number of grids is much larger than the number of measurement points, which results in the equation being an underdetermined equation with multiple solutions. Therefore, the Tikhonv regularization method is used, and the regular term is introduced to limit the range of the solution, and the equation is transformed into the least squares form:

$$\alpha = \min\{\|\boldsymbol{G} - \boldsymbol{A} \cdot \boldsymbol{m}\|_2^2 + \lambda^2 \|L \cdot \boldsymbol{m}\|_2^2\} \tag{3}$$

where α is the objective function, $L_{ij}=\omega_j \cdot \delta_{ij}$, ω_{ij} is the depth weighting function, δ_{ij} is the Kronecker function, and λ is the regularization parameter. In the expression of the depth weighting function ω_j, α is the objective function, $L_{ij}=\omega_j \cdot \delta_{ij}$, ω_{ij} is the depth weighting function, δ_{ij} is the Kronecker function, and λ is the regularization parameter. The expression of the depth weighting function ω_j is: The formula is:

$$\omega_{ij} = \frac{1}{z_j + \xi} \tag{4}$$

In the formula, z_j is the center depth of the jth grid, and $\xi>0$ can prevent the depth weighting function from generating singularities.

The physical property inversion can obtain the magnetization of each grid. According to the magnetization value of each grid, the boundary and shape of the magnetic target can be determined, and the horizontal boundary and depth information of the magnetic target can be provided for the subsequent shape inversion.

2.2. Selection of the Optimal Growth Module for Morphological Inversion

Morphological inversion is to fit the three-dimensional attitude of the magnetic target through the growing model. First, the position information and magnetic parameters of the magnetic target are calculated, and then the initial model is set according to the position information, and the corresponding magnetic parameters are assigned to build around the current model. For the region to be grown, the optimal growth module is selected according to the magnetic measurement data, and the model continues to iteratively grow until the termination condition is reached, and the final inversion result is the obtained three-dimensional pose of the magnetic target.

In the process of model growth, the optimal growth module needs to be selected in the area to be grown. Therefore, a module growth selection function is established (the minimum value of the function is taken as the optimal value):

$$\Gamma(m) = \left(\sum_{k=1}^{R} \gamma_k (m)\right) + \rho\theta(m) \tag{5}$$

In the formula, m is the magnetic parameter of the magnetic target; R is the number of data types; ρ is the regularization parameter. Since θ(m) will increase with the model growth, the constant decaying regularization parameter ρ is set for balance. In this paper, ρ Take an adaptive approach:

$$\rho_{n+1} = \mathrm{a}\rho_n \tag{6}$$

where n represents the number of iterations, set$\rho_0 = 1$, $\mathrm{a} = 0.95$.

In formula (6), γ(m) is the L2 norm of the measured data and the model forward data, which ensures that the difference between the model forward data and the measured data gradually decreases, so that the growth model is closer to the actual shape of the magnetic target; θ(m) prevents the model from growing in a certain direction by limiting the distance between the new module and the original model. The specific formulas of the above three constraint functions are:

$$\gamma(m) = \sqrt{(\zeta\boldsymbol{G} - \boldsymbol{A}m)^2} \tag{7}$$

$$\theta(m) = \frac{1}{\mathrm{x+y+z}} \sum_{p=1}^{W} \mathrm{L_p} \tag{8}$$

In the formula, ζ is the scale factor, and Am can be calculated by the forward method; x, y, and z represent the lengths of the current model in the x, y, and z axes, respectively, W is the number of modules in the current model, and L_p is the pth module. The distance from the center of the newly added module.

2.3. Establishment of Iterative Termination Conditions for Morphological Inversion

The update of the model is continuous, so it is necessary to set a certain iterative termination condition so that the model stops updating when the inversion is completed. Using the module growth selection function, the iteration termination condition can be constructed, and its expression is:

$$\mathrm{E}(m) = \frac{|\Upsilon_{new}(m) - \Upsilon_{old}(m)|}{|\Upsilon_{old}(m)|} \tag{9}$$

In the formula, $\Upsilon_{old}(m)$ is the value when the optimal growth module is not added, and $\Upsilon_{new}(m)$ is the value after adding the optimal growth module. When the iteration termination function value is less than a certain threshold, it indicates the effect of the new module on the fitting. not much, so terminate the iteration.

3. Simulation Analysis

In order to verify the influence of the prior conditions on the morphological inversion results and the applicability of the method in this paper, the following simulation analysis is carried out. Set up two sets of magnetic targets with different shapes for simulation, which are cuboid magnetic targets with length, width and height of 110m, 10m and 6m and slender magnetic targets with length, width and height of 2m, 2m and 12m, as shown in Figure 1. Show. Set the center position of the slender model to (0m, 0m, 9m), the magnetization is 40A/m, the magnetization direction is I=17°, D=50°; the center position of the cuboid model is (0m, 0m, 9m), The magnetization is 40A/m, and the magnetization direction is I=25°, D=65°; the model forward data is used as the simulated measurement data, as shown in Figures 2 and 3.

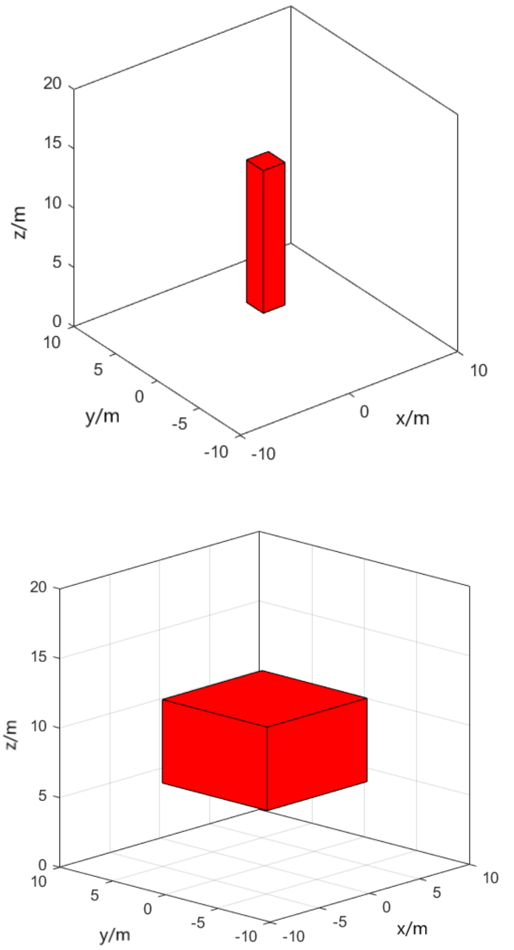


Figure 1. Schematic Diagram of the Slender Model (Left) and the Flat Model (Right)

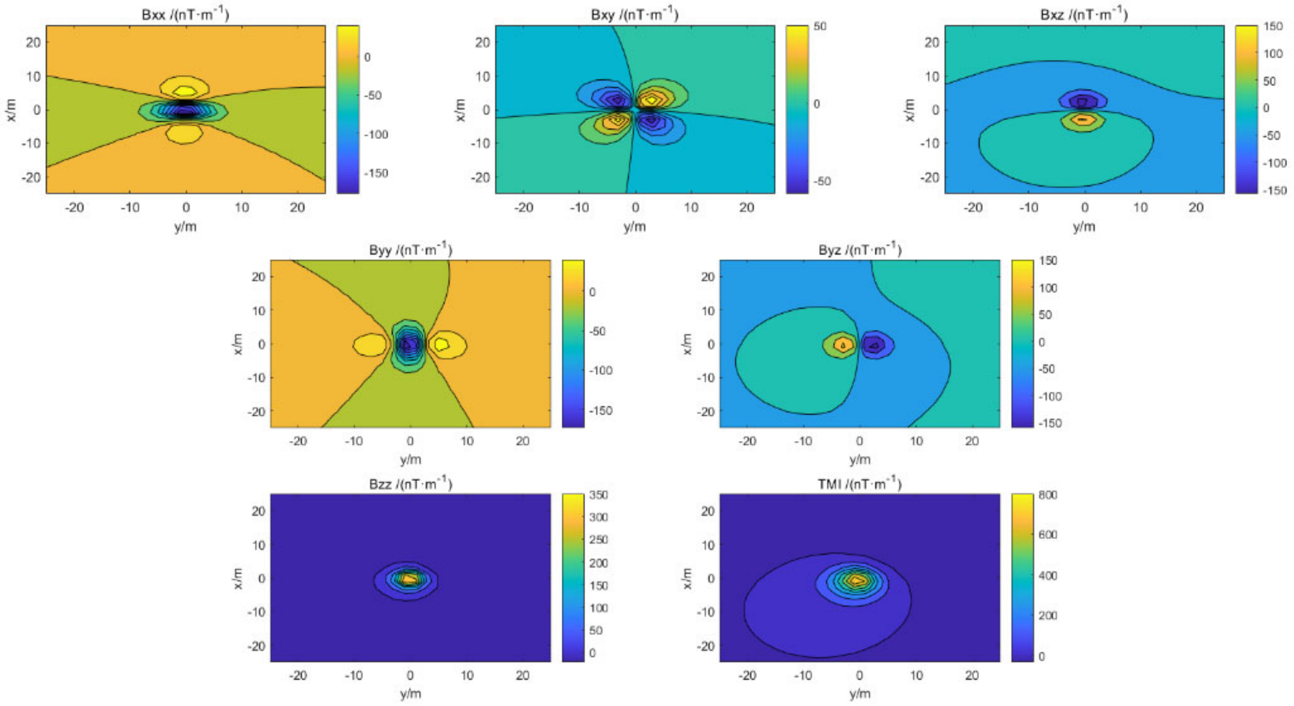


Figure 2. Forward Calculation Data of the Slender Model

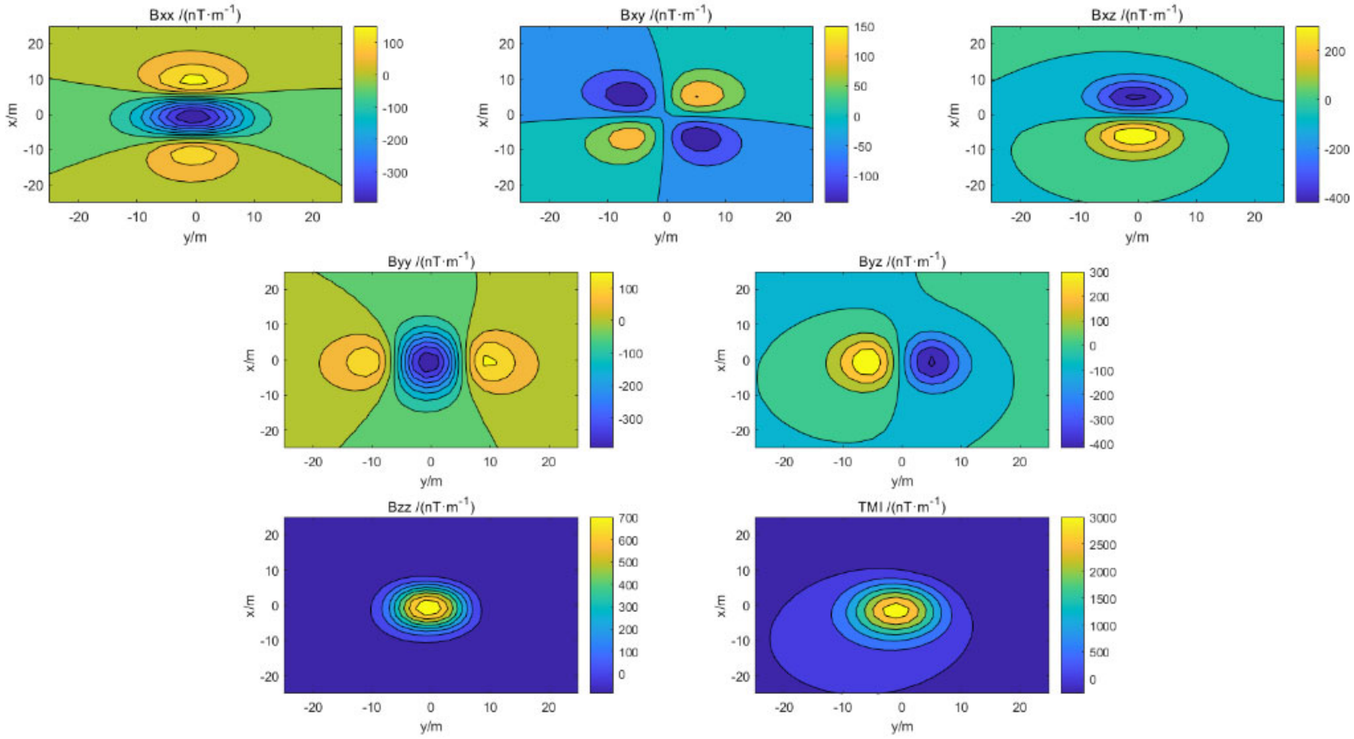
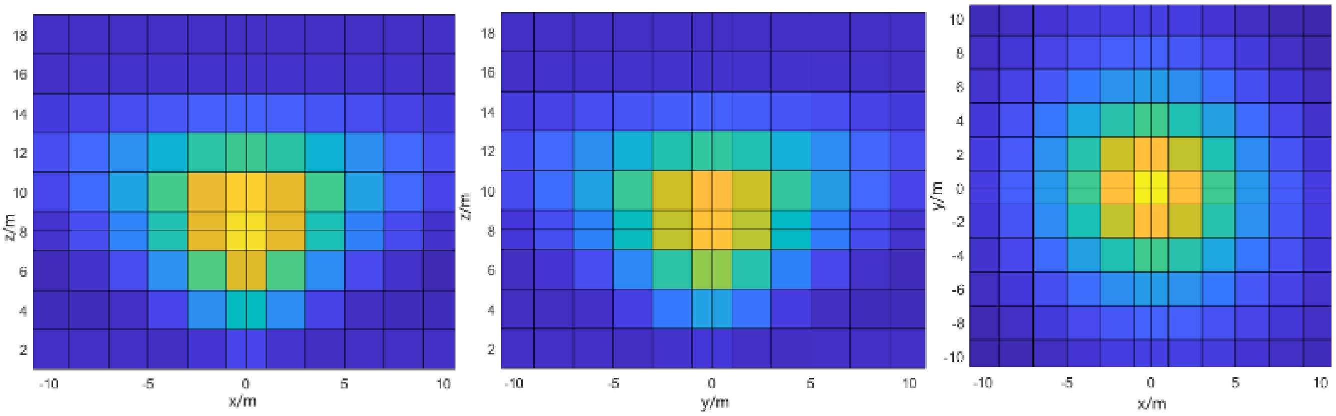


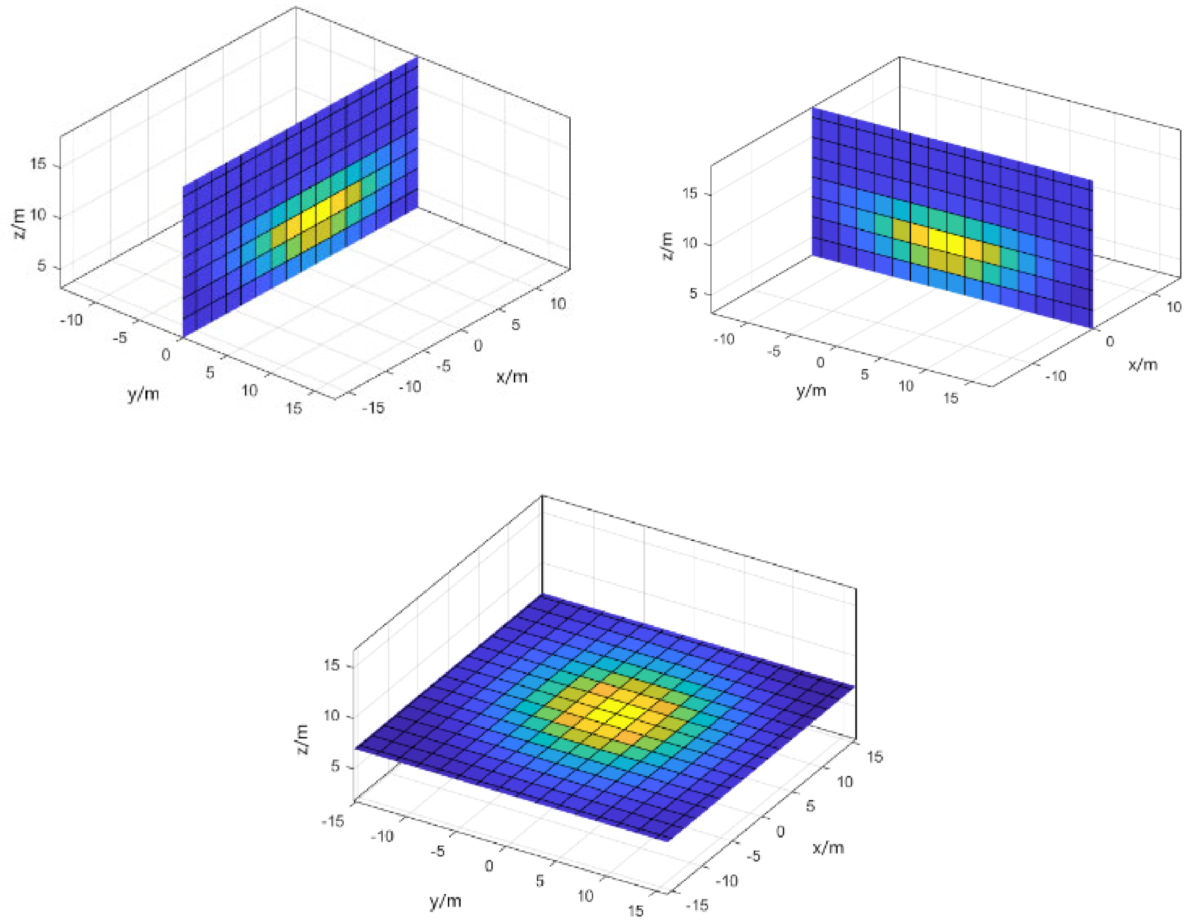
Figure 3. Forward Calculation Data of Cuboid model

Using the method in this paper to calculate the prior information of the two groups of models respectively, the calculation results show that the center position of the Cuboid model is (0m, 0m, 10m), and the center position of the slender model is (0m, 0m, 9m). The calculation results are shown in Figure 4. 5 shown. Use the obtained results to perform morphological inversion. In order to avoid being affected by the magnetization direction, the Bzz data that is insensitive to the magnetization direction is used for the inversion. Since the magnetization has little effect on the inversion results, it is not calculated separately and is set to 20A/ m, the inversion results are shown in Fig. 6. The inversion results of the two models and the RMSE statistics of the measured data are shown in Table 1.



(a) (b) (c)

Figure 4. Estimation Results of Prior Information of Slender Magnetic Target Simulation Data
(a) y=0 Direction Slice; (b) x=0 Direction Slice; (c) z=8 Direction Slice



(a) (b) (c)

Figure 5. Estimation Results of Prior Information of Cuboid Simulation Data

(a) y=0 Direction Slice; (b) x=0 Direction Slice; (c) z=9 Direction Slice

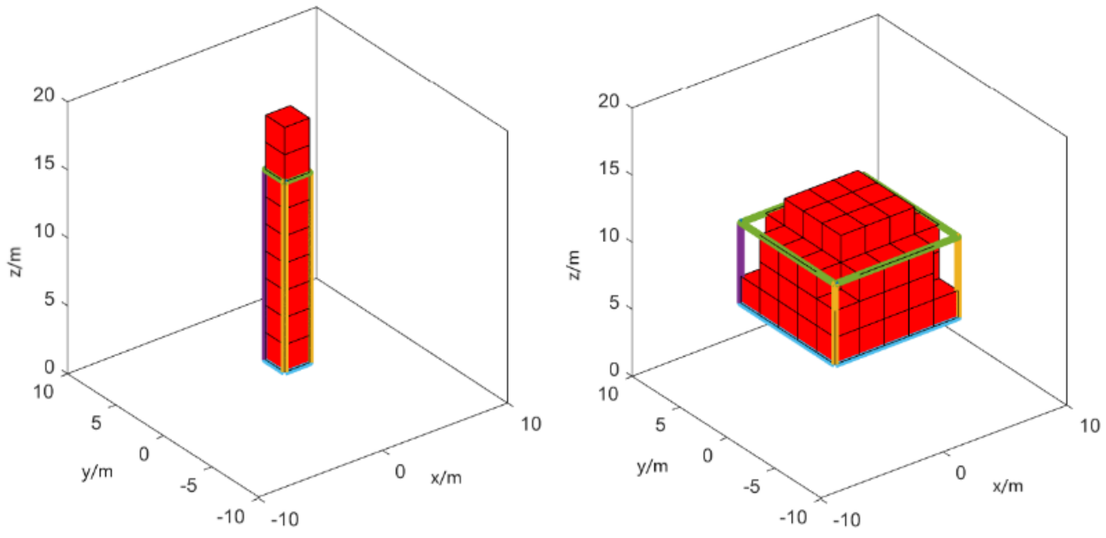


Figure 6. Inversion Results of Slender Model(left)and Cuboid Model(right)

Table 1. The RMSE Statistics of the Different Shape Models' Inversion Results and the Measured Data

Magnetic target shape	Bxx nT/m	Bxy nT/m	Bxz nT/m	Byy nT/m	Byz nT/m	Bzz nT/m
Cuboid Model	24.8166	12.2043	28.5468	21.5280	25.7548	38.5796
Slender Model	18.2684	10.5684	22.2684	18.5217	23.5464	32.1258

It can be seen from the results in Figure 6 and Table 1 that for magnetic targets of various shapes, this method can perform inversion and obtain relatively accurate results.

4. Conclusion

Aiming at the problems existing in the inversion process of the magnetic target shape, this paper proposes a shape inversion method that integrates the physical property inversion results. Then, set the parameters of the initial model, use the module growth selection function to select the optimal growth module, iteratively update the inversion model, and finally fit the three-dimensional pose of the magnetic target. The simulation and experimental results can prove the following conclusions:

(1) The method in this paper can accurately calculate that the error of the position information of the magnetic target is less than 10% of the actual value of the magnetic target, which improves the accuracy of the morphology inversion; and with the improvement of the physical property inversion method, the accuracy of the method in this paper is further increased. .

(2) For magnetic targets with different shapes, the method in this paper can determine the shape type by calculating the prior information, so as to adjust the module growth selection function and improve the applicability of the shape inversion method.

Using the physical property inversion results as prior information to perform morphological inversion can improve the coincidence rate between the inversion results and real objects, but due to the limitation of mesh division density, in order to ensure the calculation efficiency, the mesh density cannot be set too high, resulting in computational As a result, the resolution is degraded and a certain error occurs. Therefore, further optimization will be carried out to address this issue in the follow-up research.

References

[1] LI Q Z,LI Z N,ZHANG Y T,YIN G,FAN H B. Research Progress of Magnetic Gradient Tensor System and its Error Calibration [J].Journal of Academy of Armored Force Engineering. 2017(06) Page:72-81.

[2] ZHOU P Z,LI Z Y,SHEN Z Z,YIN Z X,LU X Y,HE H Z,DONG C. Research and application of magnetic detection technology for submarine optical cable[J]. Acta Scientiarum Naturalium Universitatis Sunyatseni.2021(04)Page:100-110.

[3] ZHOU Z M,QIN M,WAN F,Han Z X,Jing J J. Recognizing Coiled Tubing Defect Characteristics Based on Weak Magnetic Detection Technology[J]. IEEE Transactions on Magnetics, 2019, 55(9).

[4] Schmidt P W, Clark D A. The magnetic gradient tensor: Its properties and uses in source characterization[J]. The Leading Edge, 2006, 25(1): 75-78.

[5] M.Mosharafi,S.B.Mahbaz,M.B.Dusseault,Ph Vanheeghe. Magnetic detection of corroded steel rebar: Reality and simulations [J]. NDT and E International,2020,110(C).

[6] LI L J,Zhang X G. Discrimination method of wire rope fault signal based on Holzer sensor for multi array weak magnetic detection[J]. Cluster Computing,2019,22(2).

[7] Tsukada Keiji,Tomioka Takuya,Wakabayashi Shunki,Sakai Kenji,Kiwa Toshihiko. Magnetic Detection of Steel Corrosion at a Buried Position Near the Ground Level Using a Magnetic Resistance Sensor[J]. IEEE Transactions on Magnetics, 2018, 54(11).

[8] YIN G;ZHANG Y T;MI S L;HAN L Y;LIU M; Multiple Magnetic Targets Inversion Technique Based on Tilt Angle and Helbig Method[J]. Journal of Shanghai Jiaotong University. 2017(05)Page:577-584.

[9] Kurosh Karimi,Farzad Shirzaditabar. Using the ratio of the magnetic field to the analytic signal of the magnetic gradient tensor in determining the position of simple shaped magnetic anomalies[J]. Journal of Geophysics and Engineering, 2017, 14(4).

[10] LI J P,ZHANG Y T,FAN H B,LI Z N,YIN G,DU Y C.Focus Inversion Method Based on Normalized Source Strength[J]. Journal of Geodesy and Geodynamics.2017(10)Page:1045-1048.

[11] LI J P ,ZHANG Y T,FAN H B,LI Z N,ZHANG G.Three-dimensional Focusing Inversion of Magnetic Target in the Presence of Significant Remanence[J]. Acta Armamentarii. 2018(11) Page:2202-2210.

[12] LI Z L,YAO C L,ZHENG Y M,MENG X H,ZHANG Y W. 3D data-space inversion of magnetic amplitude data[J]. Chinese Journal of Geophysics. 2015(10) Page:3804-3814.

[13] Liu S B,Sui Y Y,Leslie Keith,Foss Clive,Clark David. Determination of the Direction of Magnetization and Orientation of a Tilted Sheet From Downhole Magnetic Gradient Tensor Data[J]. IEEE Transactions on Geoscience and Remote Sensing,2020,58(3).

[14] Liu K,Sui Y Y,Cheng H, Wang Z X,David A. Clark. Magnetic Dipole Moment Determination Using Near-Field Magnetic Gradient Tensor Data[J]. IEEE Geoscience and Remote Sensing Letters,2020,PP(99).

[15] HUANG Y S,WANG Y G,LUO X.A fast estimation method of magnetic-source parameters based on the vertical difference of normalized source strength[J]. Geophysical and Geochemical Exploration. 2021(06) Page:1588-1596.