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Integrated solutions for line planning and seafloor surface fitting in marine surveying

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Abstract. Marine surveying plays an important role in nautical safety and marine resources development. Among them, survey line planning and seafloor surface fitting are two key problems in marine surveying. In this paper, we propose a comprehensive solution to these problems. Firstly, for line planning, we establish a mathematical model for determining the shortest line in rectangular sea area, and derive the optimal line path through iterative solving. Second, for the seafloor surface fitting problem, we transformed the seafloor surface into a flat slope and established a plane-approximation surface model to calculate the line path. By visualizing the data and calculating the results, we obtained important results such as the shortest line length and the percentage of missed sea area to the total sea area to be measured. The method proposed in this paper provides an effective solution for marine surveying.

Keywords: Marine surveying; Survey line planning; Seabed surface fitting; Mathematical modeling; Iterative solution.

1. Introduction

Marine surveying is a complex and important task involving the accurate measurement of ocean topography, which is of great significance for the safety of navigation and the exploration of marine resources. In the process of ocean surveying, survey line planning and seafloor surface fitting are two key issues. Line planning involves determining the optimal line path, while seafloor surface fitting requires transforming the real seafloor surface into a mathematical model for computation and analysis. The data used in this article comes from http://www.mcm.edu.cn/. The variables and parameters involved in this paper are shown in Table 1 below.

Table 1. Symbolic representation

notation	Meaning
d_center	The line of measurement is at a distance from the center of the center point at sea level at the center point
W	Coverage width of the strip
η	Overlap rate
D	Water depth
D_center	Depth of water at the center of the line at sea level
θ	Transducer opening angle
α	Slope
β	The angle between the direction of the survey line and the projection of the normal direction of the seabed slope on the horizontal plane
γ	Angle between the line of the actual coverage width of the slope and the horizontal plane of the seabed
y	Distance of the measuring vessel from the center point of the sea area
C_center	Degree of the center point at the center of the sea area
x	Current distance from the measuring line at the center of the sea area

2. Mathematical model for the establishment of the shortest survey line in a rectangular sea area

2.1. Preparation of the model

First, we analyze the shallowest position of the line with the aim of making all the shallowest positions of the line the deepest. The deeper the depth of the shallowest position of the line, the larger the area of the sea covered by the line. Based on the information given in the question, a plan view of the deepest west and shallowest east is plotted as in Figure 1, where β is the angle between the direction of the line and the normal direction of the seabed slope projected on the horizontal plane. We analyze each line in the graph and find that to make the depth of the shallowest position of each line the deepest, then the best case is that all the lines are arranged vertically, as shown in Figure 2 below, i.e., when $\beta = 90°$, the depth of the shallowest position of all the lines is the deepest [1].

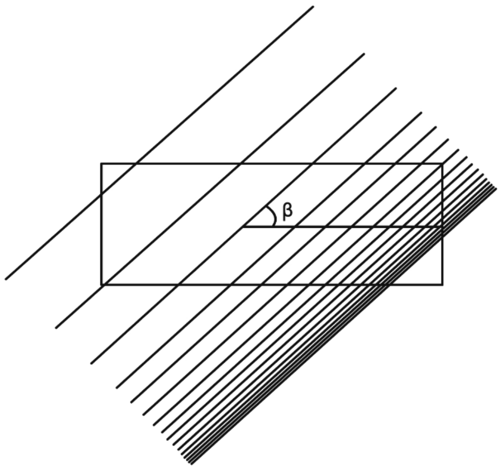

Figure 1. Schematic diagram of the line path when the angle of the line direction is β

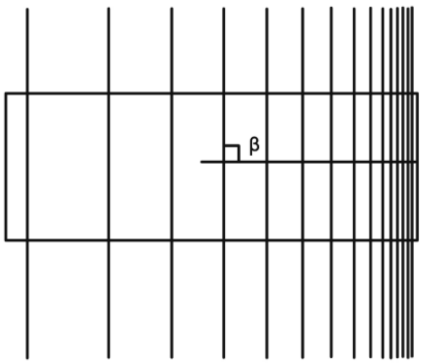

Figure 2. Schematic diagram of the line path when the angle β of the measurement line direction is 90°

2.2. Modeling

With all the lines laid out vertically, we then consider solving for maximizing the spacing between the lines. According to the text, the overlap rate is required to be between 10% and 20%, and in order to make the spacing between lines as large as possible, the overlap rate between neighboring lines should be as close to 10% as possible [2-3].

Let's start with the formula for the overlap rate from the first question and the definition of the overlap rate to get the following equation:

$$\eta(x,d)=\frac{W(x-d)-\dfrac{d*\sin(\frac{\pi}{2}+\frac{\theta}{2})*\cos\alpha}{\sin(\frac{\pi}{2}-\alpha-\frac{\theta}{2})}}{W(x)} \tag{1}$$

$$W(x)=(D\_center-x*\tan\alpha)*\sin\frac{\theta}{2}*\cos\alpha*(\frac{1}{\cos(\frac{\theta}{2}+\alpha)}+\frac{1}{\cos(\frac{\theta}{2}-\alpha)}) \tag{2}$$

Where d is the distance between adjacent survey lines, D_center is the depth of seawater at the center of the sea, x is the distance of the current survey line from the center of the sea survey line, and $x-d$ is the distance of the previous survey line from the center of the sea survey line [4].

Since it is difficult to solve for the location where the true overlap rate is 10%, we use equally spaced mini-step iterations to calculate the location where the overlap rate is closest to 10%. We group the cases into two categories to calculate: a. When the location of the survey line is at the center survey line to the east, the spacing of the latter survey line should be inferred from the coverage width of the previous survey line (the left side of the adjacent survey line). a. A is the center of the survey line, AA' is the spacing of the two adjacent survey lines, and the extension of A'B ' intersects the horizontal line B with Q, as shown in Figure 13 below. Then the length of BQ is also. By constantly adjusting the length (from west to east), iterative, so that the overlap rate is constantly close to 10%, so as to determine the width of the. b. When the position of the measuring line is in the center of the measuring line to the west, by the latter line (adjacent to the right side of the line of measurement) covering the width of the former line of measurement should be inferred with the spacing of the latter line, modeled on the case of a to solve the solution, you can determine the width of the d.Relationship Schematic is shown in figure 3.

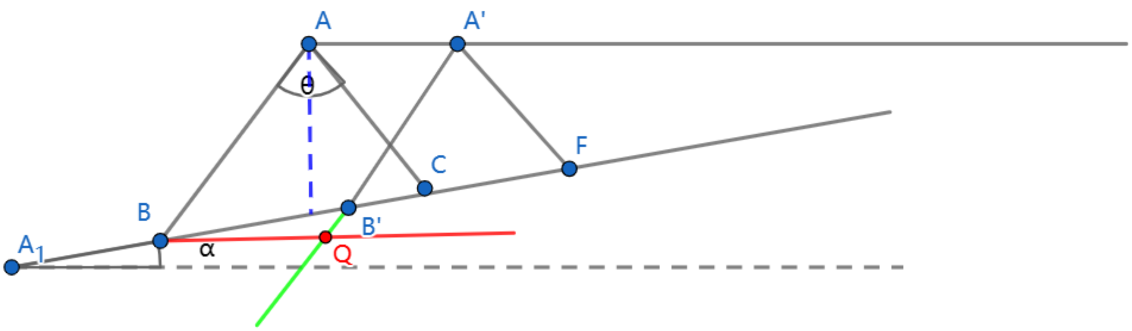

Figure 3. Schematic discussion of the relationship between overlap rate and sideline spacing

2.3. Solution results of the model

Visualization of line measurement results (figure 4):

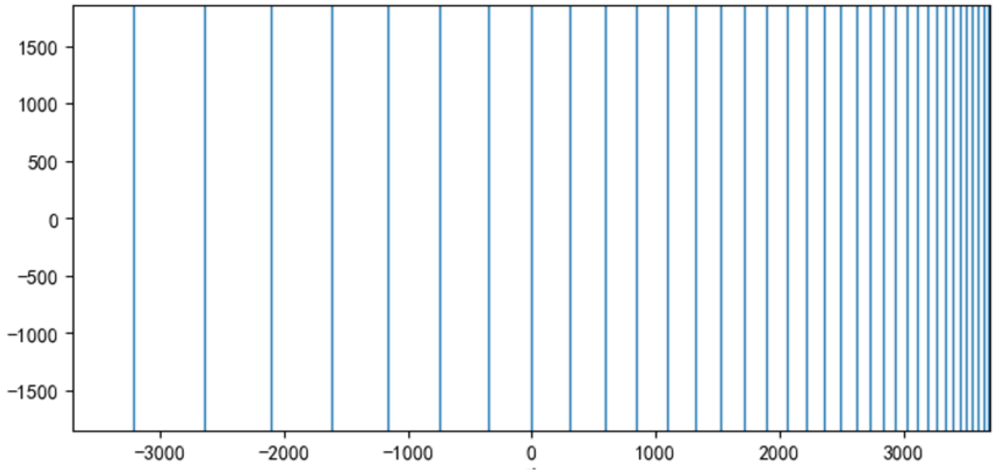

Figure 4. Schematic diagram of the output of the measurement line path

From the total number of measured routes above, the shortest total length of all measured routes is 74 marines [5-6].

3. Planar Approximation of Surface Models

3.1. Modeling

Firstly, we visualize the data, and the results are shown in Fig.5 and Fig.6. The two figures show the topography of the terrain in different directions respectively.

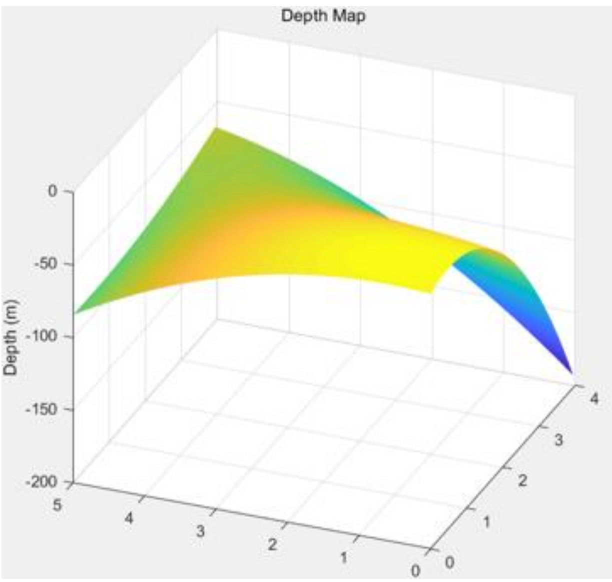

Figure 5. Image Visualization Schematic View 1

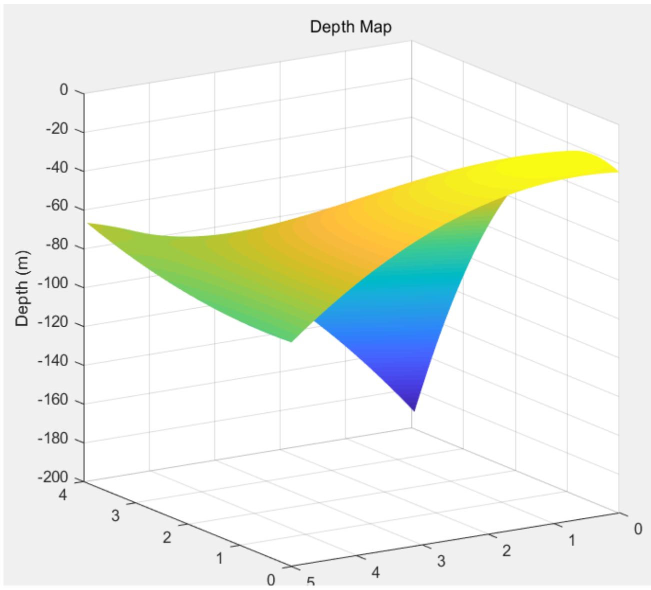

Figure 6. Image Visualization Schematic View 2

According to figure 7 and 8, the seafloor in the sea area is a continuous irregular surface, by converting the surface into a flat slope, connecting the higher part of the middle area with a straight line as the dividing line between the two slopes, and replacing the surface with two plane triangles to approximate the surface, with the angle of each triangle with the horizontal plane as the angle of the respective slopes [7].

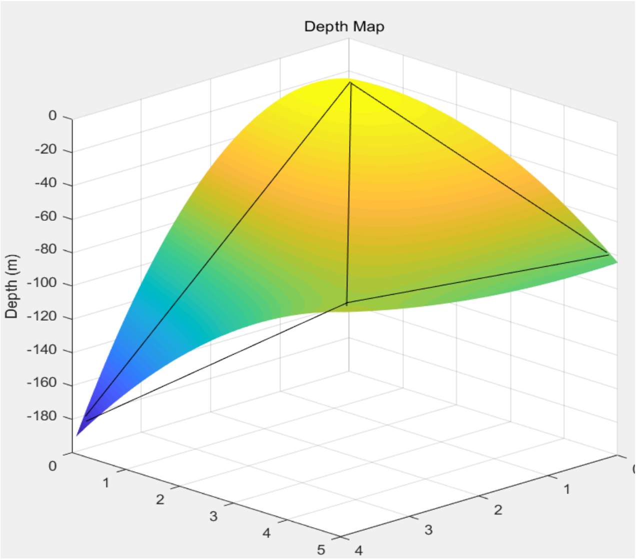

Figure 7. Schematic View of Problem Four Plane Fit Surface 1

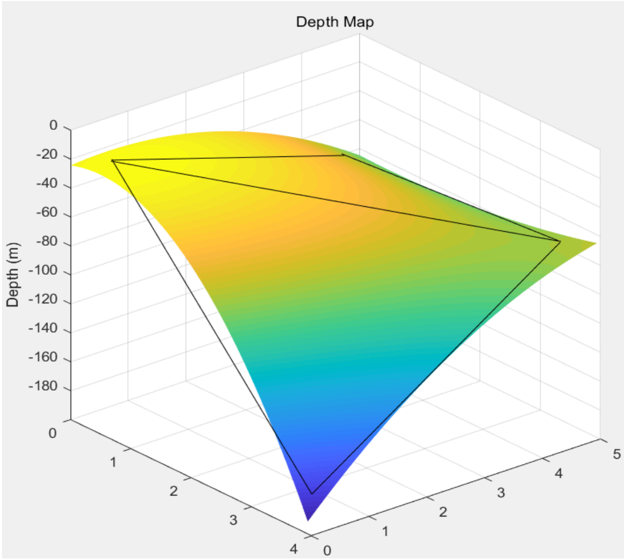

Figure 8. Schematic View of Problem Four Plane Fit Surface 2

To address the question of line direction, the direction of projection of the horizontal plane where the middle dividing line of the two triangles is located can be taken as the direction of the line, because similar to the analysis of sidereal direction in the third question, only the line following the direction of extension of the contour line can scan as much as possible to cover a larger area [8].

The triangular composition made from the top view of this sea area covers exactly the whole rectangular sea area. Observe and analyze the surface, we can clearly see the surface ABC slope is less than the surface BCD, so on the surface ABC to make and B point at the height of the contour line BB', that is, BB' for the direction of the line of measurement, and now through the purely geometric method of finding out $BB':(0,3.4)$, and then through the B' to do the BB' of the perpendicular line of the $B'E$ intersecting the BC in the E.

$$\begin{cases} \angle CBA = arctan\dfrac{CA}{AB} \\ \angle B'BA = \arctan\dfrac{B'A}{AB} \end{cases} \tag{3}$$

From this we can derive:

$$\angle EBB' = \angle CBA - \angle B'BA \tag{4}$$

Because a right-angled triangle $\Delta ABB'$

$$BB' = \sqrt{AB^2 + B'A^2} \tag{5}$$

So we end up with

$$BE = \frac{BB'}{\cos(\angle EBB')} \tag{6}$$

Substituting the data you can find that BE is about 4.95 nautical miles, which gives a depth of about 33.65 meters from the bottom at point E.

$$B'E = \sqrt{BE^2 - BB'^2} \tag{7}$$

Get $B'E$ is about 4572.24 meters.

The degree of the slope is now 0.3998. Now that the angle of the slope has been obtained, it is possible to directly apply the model developed to the calculation of the coordinates of the survey line. The final result of this calculation is as figure 9.

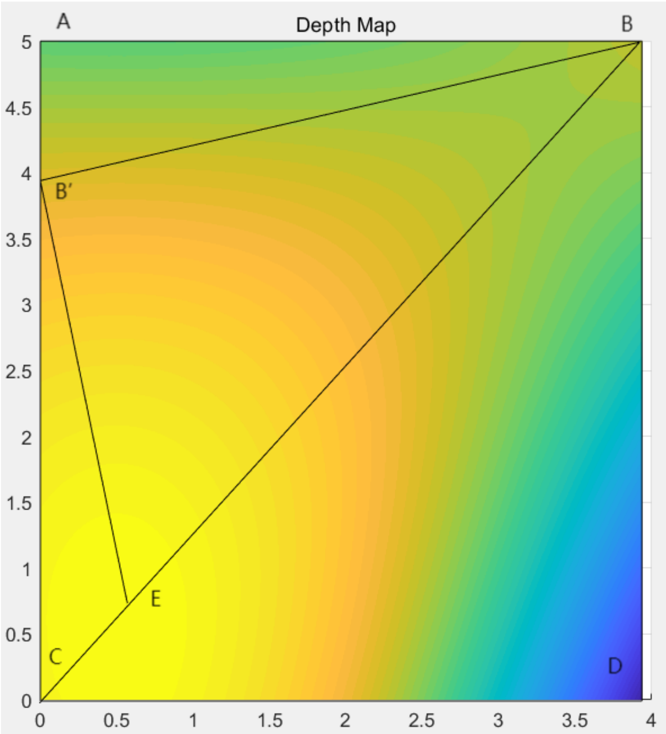

Figure 9. Top view of visualized data

Tanle 2. The optimization idea based on this model

Minimum line length (m)	573771.161
Percentage of missed sea area to total sea area to be measured	0%
Percentage of overlapping area exceeding 20	28%
Total length of the part with more than 20% overlap (m)	162729.216

Because using only two triangular planes to approximate the existing 3D surface will result in an inadequate fit that does not ideally fit the real surface, the designed line paths are not optimal for the real terrain. In order to achieve a better fit to the terrain, it is possible to consider approximating the real surface with more small square planes with smaller individual areas, thus increasing the degree of fit. So optimization algorithms such as particle swarm can be used to optimize the solution.

3.2. Summary

The optimal route solution under the condition of using two triangular planes to approximately fit the surface is used, the model established under this condition is more rough and simple, and can not be well applied to the optimal route design of real surfaces, for this reason, at the end of the problem, it is proposed to use more small square planes to fit the surface, and the smaller the side lengths of the squares are set, the better the effect of the fit to the surface will be, but it also would lead to a skyrocketing increase in model complexity. It is envisioned that a balance between fit and model complexity can be maintained by setting a reasonable number of small square edges to achieve a better fit to the real surface in the optimization algorithm and to improve the accuracy and feasibility of the model.

4. Conclusion

The comprehensive solution proposed in this paper effectively solves the problems of line planning and seabed surface fitting in marine surveying. By building a mathematical model and adopting an iterative solution method, we have successfully derived the optimal survey line paths and effectively fitted the seabed surface. We have derived a series of important computational results, which provide important reference and support for oceanographic surveying. In the future, we can further optimize the model to improve the solution efficiency and accuracy to cope with more complex oceanographic measurement tasks.

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