Research on the optimization of multibeam detection system wiring based on genetic algorithm

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Abstract. The multibeam bathymetric system is an advanced sonar technology that can simultaneously measure the depth of multiple underwater locations and is widely used in marine science and seabed resource exploration. It is of great significance to science, technology, social development, and marine environmental protection. In this paper, the fundamental theory of biology is combined with the cabling optimization model of a multibeam bathymetry system to accurately plan the cabling. Firstly, this paper uses geometric analysis to analyze the relationship between coverage width, edge spacing, and overlap rate, and the relationship between coverage width and seawater depth. Secondly, this paper develops a single optimization model that takes the minimum total length of the wiring as the objective and the full coverage of the sea area and the range of the overlap rate as constraints. Finally, the optimal solution is approximated using a genetic algorithm and visual analysis of the results is conducted. The results show that the overall wiring error is small, and the optimized wiring layout model holds a certain reference value and significance.

Keywords: Genetic Algorithm, Optimization Model, Correlation Analysis.

1. Introduction

Accurately planning the wiring of a multibeam bathymetric system holds significant importance in observing electromagnetic fields in the seabed, offshore operation technology of electromagnetic methods, and analyzing and processing data [1-6]. Effective seabed exploration research requires precise multibeam bathymetric system cabling, which directly affects the accuracy of subsequent seabed topographic data analysis. This is crucial for accurate seabed topographic estimation, development planning, and cost reduction. This paper's wiring optimization model, which uses a genetic algorithm to determine the shortest path of wiring, contributes to achieving these goals [7-8]. The traditional multibeam bathymetry method establishes an integer planning model for integrated wiring decision-making [9-10]. It also creates a three-dimensional information model of the underwater bottom in the target waters and accomplishes the coordination of common and shortest paths through weighted combinations. Nevertheless, these methods have their limitations.

2. Model Construction

Genetic algorithm is a kind of adaptive artificial intelligence optimization algorithm based on the theory of biological evolution, and its basic idea is to find the optimal solution by simulating natural selection and genetic mechanisms. This paper primarily applies to solve complex solution spaces.

The optimization objective in this paper is to determine the total length of the wiring, the decision variables in this model measure the x and y coordinates of the paths, and the constraints are: The strip is scanned along the survey line covers the whole sea area to be measured as much as possible. To prevent leakage and to ensure the integrity and convenience of the measurement data, the overlap rate η should be such that it is at 10 % ~ 20%.

2.1. Model Preparation

We find that when the lateral lines are parallel to each other and the seafloor topography is relatively flat, there is a relationship between the coverage width w, the lateral line spacing d, and the overlap rate η:

$$\eta = 1 - d/w \tag{1}$$

And there is also a relationship between the coverage width w, the seawater depth h, and the transducer opening angle θ as follows:

$$w = 2 \times h \times \tan\frac{\theta}{2} \tag{2}$$

The fitness function is built by maximizing the percentage of covered area, minimizing the total length of the line, and minimizing the length of the overlapping area over 20%. Define the fitness as f, the coverage area as c, the total length of the line as t, and the length of the overlapping area exceeding 20% as o, w1, w2, and w3 are the corresponding weighting coefficients.

$$f = w_1 \times c - w_2 \times t - w_3 \times o \tag{3}$$

Define a single chromosome as a collection of measured lines, where each line is represented by start and end coordinates.

2.2. Model Building

In this paper, a single-objective optimization model is developed to minimize the total length of wiring:

$$\sum_{i=1}^{n-1} \sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2} \tag{4}$$

Where x and y are the coordinates of the start and end points of each line, and n is the number of coordinate points in the path F.

2.3. Restrictive Condition

The strip scanned along the survey line covers the whole sea area to be measured as much as possible. In order to prevent leakage and to ensure the integrity and convenience of the measurement data, the overlap rate η > 0 should be made such that it is at 10% ~20%.

3. Solutions

The general model of genetic algorithm consists of five basic elements, and its flow is shown in Figure 1.

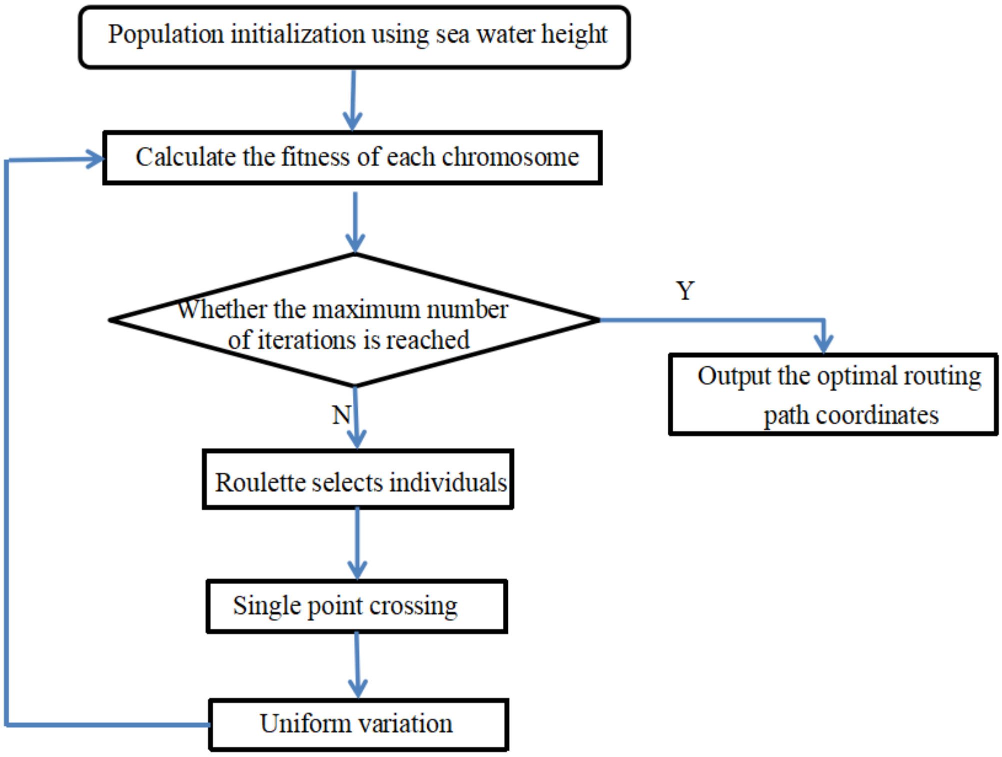

Figure 1. Genetic algorithm flow chart

3.1. Initialize the population

A set of chromosomes is randomly generated, and the position of each gene on the chromosome is determined by the starting value and gene distance of the multiple sets of chromosomes that make up a population.

3.2. Individual Adaptation Evaluation

Calculate individual evaluations or estimate the fitness of each individual in a population. The function will calculate the total path length and calculate the fitness based on that length. The shorter the path length, the higher the fitness, and finally the function returns the fitness value.

3.3. Selection of outstanding individuals

Apply selection operators to the population. Inherit optimized individuals directly to the next generation or generate new individuals by pairwise crossover and then to the next generation. The selection operation is based on the assessment of the fitness of the individuals in the population.

3.4. Design of genetic operators

Apply the crossover operator to the population. Set up only one random crossover point in the coding of individuals, and then exchange parts of the chromosomes of two paired individuals with each other at that point to produce two new individuals.

Apply the variation operator to the population, make changes to the values of genes at specific loci in a string of individuals in the population.

3.5. Judgment of termination conditions

If the maximum number of iterations is reached, the individual with maximum fitness obtained during the evolutionary process is output as the optimal solution and the computation is terminated.

4. Results

Let's say there's an ocean. The two-dimensional and three-dimensional visualization results of the sea area are shown in Figure 2 and Figure 3 respectively.

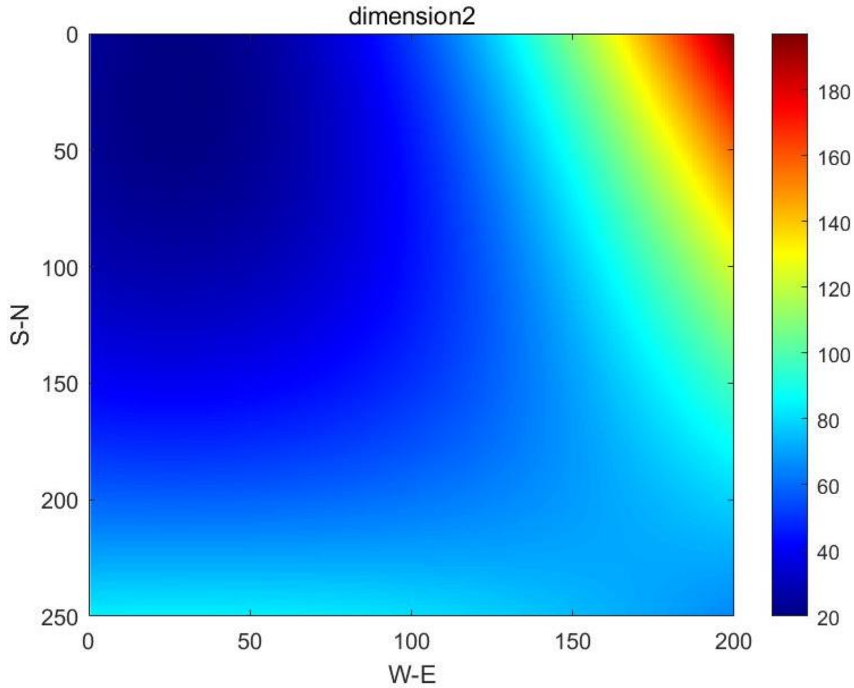

Figure 2. Two-dimensional sea map

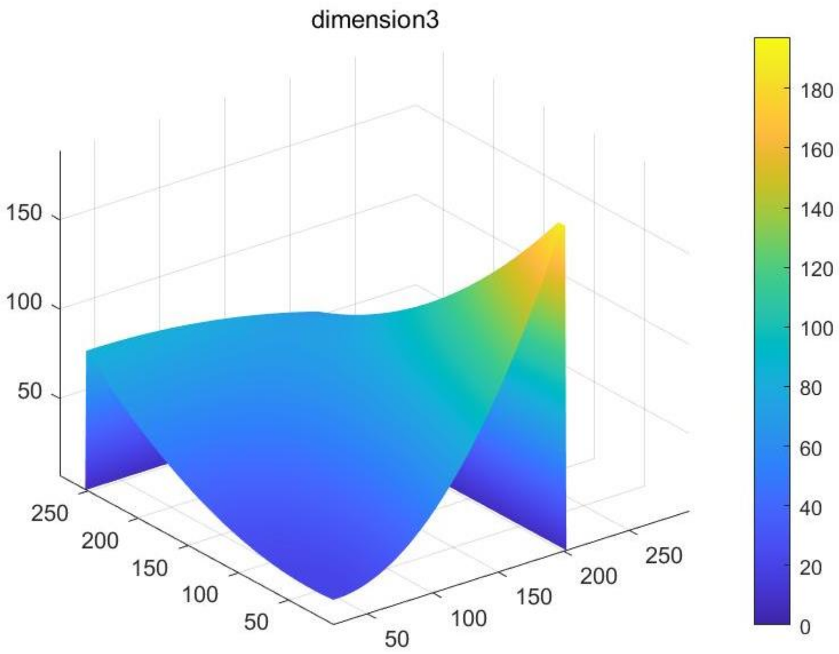

Figure 3. Three-dimensional sea map

The x and y coordinates of the optimal path in this sea area are shown in the table below, where the first ten coordinate points are selected, as shown in Table 1.

Table 1. Coordinate diagram of the optimal path

x	403.2136	623.4181	1023.015	1505.091	1809.571	2092.381	2752.774	3180.429	3016.177	4345.866
y	22.33975	426.8769	753.9281	1314.34	1764.833	2027.069	2309.043	2799.86	2669.383	3048.361

The visualization results of the optimal routing path in this sea area are shown in Figure 4.

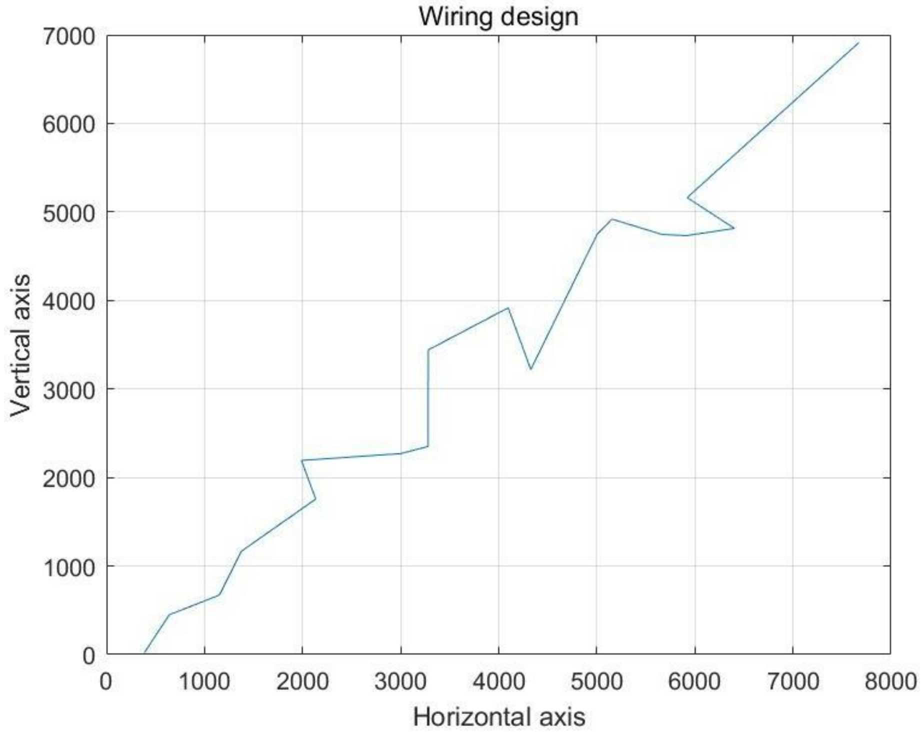

Figure 4. Result chart

The genetic algorithm considers multiple wiring schemes at once and optimizes them through selection, crossover, and mutation until the optimal solution is found, during which the algorithm can automatically adjust its direction to find the best wiring scheme with negligible overall wiring error. The paths solved by the genetic algorithm can be examined to obtain the number of wiring coordinate points, the total length of the wiring, the percentage of the area of the sea area with omission of wiring, and the percentage of the area of the sea area with an overlap of more than 20%, and the results are reasonable and able to meet the requirements. The calculation results are shown in Table 2.

Table 2. Wiring result parameter

Number of wiring coordinate points	Length of wiring (m)	Percentage of missing sea area (%)	The overlap rate exceeds 20% of the sea area (%)
22	13,442.1864	13.506	0.07

5. Conclusion

The model developed in this paper has high accuracy, beautiful and easy to distinguish visualization graphics, and is widely applicable to other fields such as astronomical detection, medical examination, engineering measurement, and geological detection, etc. It is also highly accurate and precise, and can provide reliable data results for the detection staff. However, in reality, there are many uncontrollable factors that may affect the actual data and lead to errors. The coverage width model, seawater depth model, and three-dimensional geometric analysis methods developed in this paper are not only widely used in oceanographic field, but can also be applied in the fields of building surveying and terrain analysis to provide accurate data for the relevant staff to improve the efficiency and accuracy of terrain surveying.

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