Development of layout algorithm for pipeline, considering topographic features

P V Grigorieva, K S Voronin1 and D A Cherentsov

Industrial University of Tyumen, 38 Volodarskogo St., Tyumen, 625000, Russia

E-mail: polino4ka.g@yandex.ru, voronin_tsogu@mail.ru, cherentsovda@bk.ru

Abstract: In the article algorithms of path-tracing are considered; the developed algorithm for searching the optimal pipeline route is presented, taking into account topographical features of site.

1. Introduction

Drawing up the route plan is an obligatory stage in the pipeline design. This issue is considered at the stage of route location, which consists of a complex of engineering and geodesic activities to find the path. Route location includes two main elements [1-3].

The first is a route plan which is an exact projection of the route on the horizontal plane.

The second is a longitudinal profile of the route, which is its vertical section along the projection line [4, 5]. This plan consists of segments of straight lines with different slope ratio, which can be connected by circular curves if necessary.

An ideal route should be straightforward, without deviations and bends, which can lead in practice to a significant increase in the cost of construction and its operation. However, the direct and longitudinal plans most often do not correspond to each other, and subsequently these discrepancies are solved by curving the general plan of the path (curves of constant and variable radius of curvature). So, the plan should reflect the trajectories of bypassing sites with negative geological conditions, large slopes and other unfavorable obstacles [9-12].

It is not always possible to take into account the structure of topographic features at the initial stages of compiling the path of the main pipeline route, carried out on small-scale topographic maps.

At present, designing of pipelines is a difficult task. There are many options for passing the pipeline route between the start and end points. The choice of the route is more often based on the expert opinion of the technicians developing the project documentation. However, automating the search for a route with the lowest capital costs is an urgent task [7].

2. Materials and methods

There are many different algorithms to solve the problem of finding the path between the start and end points. Their comparison is presented in Table 1. These algorithms differ in the following characteristics: the accuracy of the trace performing, the performing speed of the algorithm, the number of limits taken into account and the requirements for pipeline design. The following trend is clearly traced in these algorithms: the more accurately the algorithm performs the tracing, and the more rules it takes into account, the slower is its performance, and vice versa, the faster the algorithm

performs, the less precise decisions it gets. The task is to create an algorithm that will most quickly and accurately route the pipeline on a map, taking into account the topographic features of the site [8]. The wave algorithm was chosen as the basis of the created algorithm, as it can find a path under any conditions and is fairly simple in its use.

Table 1. Comparison of algorithms for pipeline route location

Algorithm	Algorithm A*	Dijkstra's algorithm	Wave algorithm
Advantages	1.Combines the length of the previous path. 2.Takes into account the cost to the target point.	1. High speed of performance. 2. Calculation of ribs with a negative weight 3. High accuracy of result.	1. The best path will be always found. 2. The possibility of introducing the cost of the cell. 3. The possibility of constructing a path not to one but directly to several goals, that is, the search for the nearest target is in progress. 4. The clarity and simplicity of the algorithm.
Disadvantages	1. Memory limitations. 2. It takes a lot of process time.	1.Complexity of understanding. 2.On each pass, it takes into account the length of only one rib.	1. A large amount of memory is required.

The process of building a route can be divided into 2 stages [8].

1. The wave transmits in the 4 directions from the initial element. The element in which the wave came is the front of the wave. In Fig. 1, numbers indicate the wave front numbers.

Each element of the first wave front is the source of the secondary wave. Elements of the second wave front generate a wave of the third front and so on. The process continues until the end element is reached or until it becomes clear that it can not be achieved.

2. The route itself is constructed. Its construction is carried out from the final element to the initial one.

The initial task of finding the path for laying the pipeline layout is to apply a grid and "weight" of cells to the site of the map. The "weight" of cells is selected in accordance with the criteria of optimality: the reduced costs; the pipeline length; labor costs; reliability of pipeline operation; time of construction as well as the cost of laying the pipeline taking into account the site features.
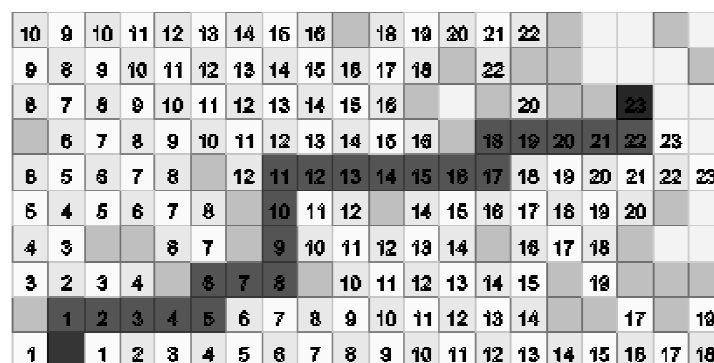

Figure 1. The result of the wave algorithm

Then the matrix with the "weights" of the grid is transferred to the developed program, where the laid path with the optimal costs is shown by simple pressing the button.

To implement the wave algorithm, a flow chart has been developed (Fig. 2a), which looks like this:

the initial (input) parameters are given. This is the dimension of the grid (matrix), the initial and final points of the trace and the "weight" applied to the grid, taking into account topographical features. The essence of the developed algorithm is to perform the task: to lay the optimal path from the initial to the final element. For this, a recursive function will be used, i.e. if the condition, where the start point is equal to the final one, is not fulfilled, let us move to the other cell along the X and Y axes and add the "weight" of the cell to which the existing sum is added. That should be done until the extreme point is reached. At the end, the minimum amount of "weights" is displayed [8].

The algorithm was implemented in the VBA language. The choice of this particular language was based on the ease of transferring the "matrix" of the terrain map to Excel electronic work sheets.

Fig. 2b shows the grid with the applied "weights" and the results of the shortest distance found on the map using the implemented wave algorithm. For a more detailed study of the route, it is necessary to share the map into smaller cells, i.e. create a matrix containing more elements.
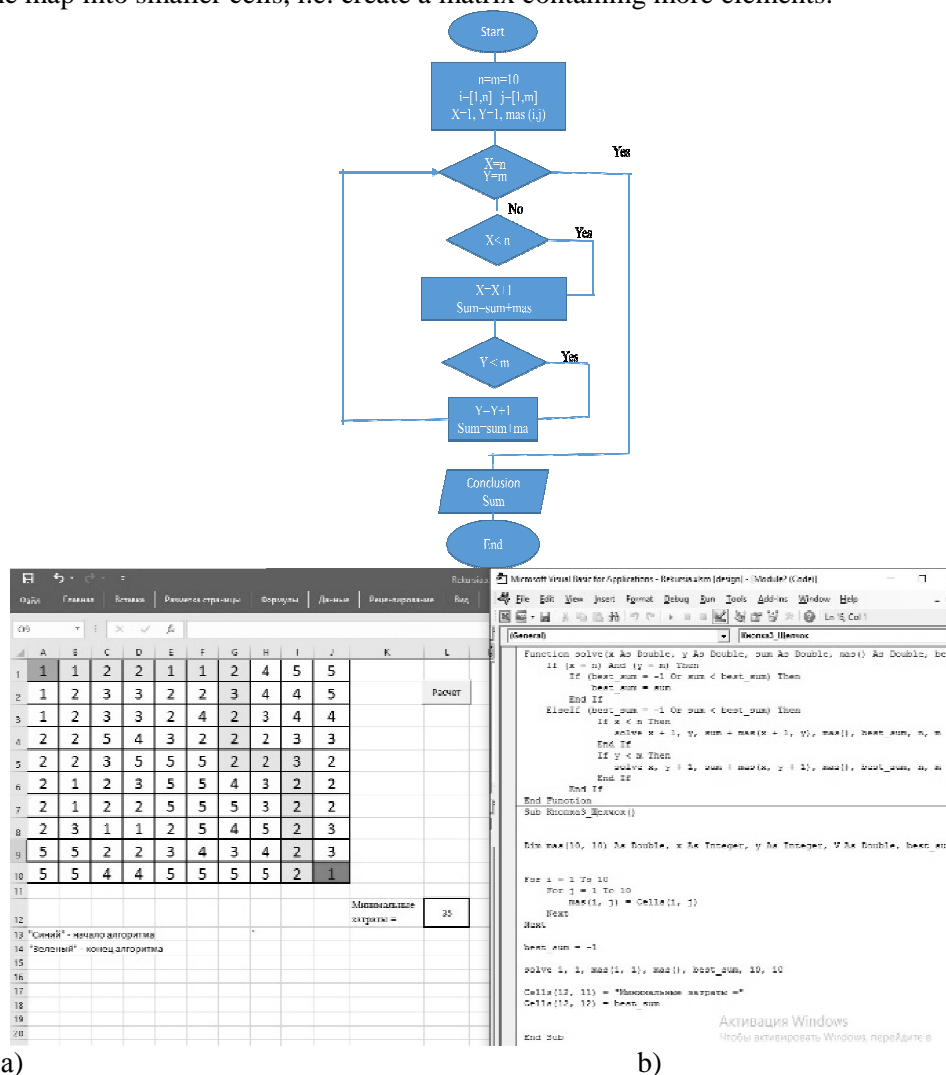

a)　　　　　　　　　　　　　　　　　　　　b)

Figure 2. A flow chart and implementation of the wave algorithm in the VBA language

The resulting pipeline route, using the developed algorithm, is angular, because 4 directions were used. To correct this, one needs to divide the grid into smaller cells, or use the interpolation function, i.e. one finds approximate values of the obtained trace for values of variable x that are different from the interpolation nodes [6]. To do this, let us use interpolation with splines: one of the most common cases in practice is a cubic spline.

On each of segments $[x_{i-1}, x_i]$, $i=1, 2, ..., n$ let us search for spline function $s(x)=s_i(x)$ in the form of a polynomial of the third degree:

$$s_i(x) = a_i + b_i(x - x_i) + \frac{c_i}{2}(x - x_i)^2 + \frac{d_i}{6}(x - x_i)^3,$$

$$x_{i-1} \leq x \leq x_i, i = 1,2,...,n \tag{1}$$

where a_i, b_i, c_i, d_i are the required coefficients, which are found by differentiating function $s(x)$ on x $a_i=s_i(x_i)$, $b_i=s_i'(x_i)$, $c_i=s_i''(x_i)$, $d_i=s_i'''(x_i)$:

$$a_i = a_{i+1} + b_{i+1}(x_i - x_{i+1}) + \frac{c_{i+1}}{2}(x_i - x_{i+1})^2 + \frac{d_{i+1}}{6}(x_i - x_{i+1})^3, i = 0,1,2,...,n-1. \tag{2}$$

Denoting $h_i=x_i-x_{i-1}$ and omitting the intermediate operations, let us finally obtain a system of equations for determining coefficients c_i:

$$hc_{i-1} + 2(h_i + h_{i+1})c_i + h_{i+1}c_{i+1} = 6(\frac{y_{i+1} - y_i}{h_{i+1}} - \frac{y_i - y_{i-1}}{h_i}), i = 0,1,2,...,n-1. \tag{3}$$

$c_0 = c_n = 0$.

Since the coefficient matrix is tridiagonal, system (3) has a unique solution. Having found coefficients c_i, let us define the remaining coefficients by the explicit formulas:

$$d_i = \frac{c_i - c_{i-1}}{h_i}, b_i = \frac{h_i}{2}c_i - \frac{h_i^2}{6}d_i + \frac{y_i - y_{i-1}}{h_i}, i = 1,2,...,n. \tag{4}$$

3. Conclusion

Thus, the developed algorithm for finding the optimal pipeline route according to the proposed criteria, taking into account topographic features, possible unforeseen emergency situations and potential economic losses will allow selecting the most rational option as well as significantly improving the quality of the taken decisions.

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