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ORIGINAL RESEARCH ARTICLE

Automatic matching of multi-scale road network under the constraint of small-scale road mesh

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ABSTRACT

Aiming at the problem of road network multi-scale matching, a multi-scale road matching method under the constraint of road mesh of small-scale data has been proposed. First, two road meshes with different scale data are constructed; Secondly, under the constraint of the small-scale road mesh, the composite mesh composed of several road meshes in the large-scale road is extracted, and the mesh matching with the small-scale road mesh is completed; Then, many-to-many matching of road meshes with different scales is realized; finally, the matching relationship between composite mesh and small-scale road mesh is transformed into the matching between multi-scale road mesh boundary roads and internal roads, and the matching of the whole road network is completed. The experimental results show that this method can better realize the matching of multi-scale road network.

Keywords: Multiscale Matching; Road Network Matching; Road Mesh

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1. Introduction

Scale is an important feature of geographic data[1]. Different scales of data have differences in morphological features, detail information and abstraction, which makes the multi-scale expression of spatial data one of the difficulties restricting the application of GIS[2-4]. The purpose of multi-scale representation of spatial data is to solve the contradiction between discrete data and continuous display. At present, there are two main mechanisms for the establishment of multi-scale expression databases: one is the static multi version method, and the other is the dynamic online method[2,5].

The ideal multi-scale expression method is to directly and automatically synthesize a single large-scale vector data to generate arbitrary small-scale vector data. However, due to the international problem of automatic synthesis, no breakthrough has been made, so the establishment of multi-scale expression database under existing conditions is mainly based on the static multi version mechanism[6,7]. The traditional multi-scale expression based on the key scale has a large jump between data, which cannot give users a continuous visual experience. With the deepening of research, in order to solve this problem, the basic scale data participate in the intermediate scale. It is considered a more reasonable way for the base scale data to participate in the generation of new data for the intermediate scale. The means of realization is to interpolate between adjacent scale data to generate the expression of intermediate scale. The generated interpolation data should reflect the characteristics of the scale data at both ends at the same time, so it is necessary to establish the relationship between the scale data at both ends, which leads to the problem of multi-scale matching. Spatial data matching technology must be used to establish the connection between the scale data at both ends. Spatial data matching is the core technology of spatial data integration and updating, which refers to identifying the same ground object in the spatial data set from different sources in the same region by measuring the similarity of the geometry, topology and semantics of the target[8,9].

As one of the most important geographical elements, road network is the focus of multi-scale expression research. For a long time, many researchers have studied the road matching algorithm. Based on the basic idea of probability and statistics, Walter and Fritsch[10] performed geometric matching on road data. Its core is to calculate the matching probability of candidate targets within a certain range, and take the maximum probability as the matching result, which belongs to the typical buffer growing[11-13]; Volz[14] and Goesseln GV[15] used iterative geometric matching algorithm to match GDF navigation data with German ATKIS road data, which belongs to iterative closest point method. The former is a road network matching method based on road arcs, and the latter is a road network matching method based on road nodes. The existing road network matching basically belongs to these two kinds of methods, or is based on the combination and improvement of these two kinds of methods. Liu, Qian, Wang, *et al.*[16] adopted the analytic hierarchy process to conduct the overall analysis of the road network, automatically assigned weights to the similarity evaluation indicators of roads, evaluated the overall similarity of roads, and completed the automatic matching of roads. Cheng, Gong and Shi[17] proposed a matching algorithm based on the distance of multi-scale road network, which converted the calculation of geometric similarity between complex broken lines into the calculation of the distance from nodes to broken lines, and improved the calculation efficiency by establishing grid index. Zhao and Sheng[18] proposed an automatic matching method of vector road network for global optimization, which comprehensively utilized the characteristic information of road arcs and nodes, established an optimization model, and used the probability relaxation method to solve the optimal solution to obtain the matching relationship between road arcs. Luan, Yang and Li[19] extracted the local network pattern characteristics of road nodes through the structural description of road intersections, and calculated the morphological similarity between nodes for road matching.

Traditional methods are mostly based on the evaluation of the overall similarity between roads with the same scale, but under the condition of multi-scale, the morphology of roads with the same name has obvious differences. Under the condition of missing attribute information, the use of geometric features to extract the road as a whole is often in errors, which cannot guarantee that the road data with different scales can extract the same road as a whole. Therefore, the similarity evaluation system established by using multiple indicators may not achieve satisfactory matching results. To solve this problem, this paper proposes a multi-scale road automatic matching algorithm based on the constraint of small-scale road mesh. First, the matching relationship between large-scale road mesh and small-scale road mesh should be established, and then the matching between roads with the same name at different scales could be completed by using the matching relationship of road mesh as a constraint.

2. Road mesh multi-scale matching model

The matching research in this paper mainly focuses on the multi-scale road network data with simple morphology, and does not consider the matching between the road network data with complex structures and double track roads.

2.1 Definition of road mesh

The roads in the map are crisscrossed, dividing the map into several independent area areas, which constitute the road mesh. Road mesh is not a specific geographical element, but an object abstracted by people in the process of studying intelligent selection of road network, multi-scale vector spatial data matching, automatic road synthesis algorithm, etc., in order to facilitate the expression and description of the spatial structure characteristics of road network[20].

The hierarchy of the road determines the hierarchy of the road mesh enclosed by the road. The high-grade roads form the main division of the spatial area, thereby forming a higher-grade mesh, and the low-grade roads form the secondary division of the spatial area, thus forming a low-grade mesh. The most typical example is the "urban block system". In order to distinguish the hierarchy of road mesh, the road mesh is divided into basic road mesh and composite road mesh according to its complexity. The basic road mesh is the smallest unit of the morphological structure decomposition of the road network, such as a, B, C, D in **Figure 1**. Its basic feature is that there are no other roads within the mesh to effectively segment it. There are many roads inside the composite road mesh to divide the area where the road mesh is located to form other road meshes. In fact, the composite road mesh is composed of two or more road meshes. For example, road meshes a, B and C are further merged from the smaller meshes in **Figure 1**. The composite mesh is not simply composed of any adjacent basic mesh at will. The boundary roads that form the composite mesh form the main segmentation of the space area Compared with the internal road of the composite mesh, it has a higher level.

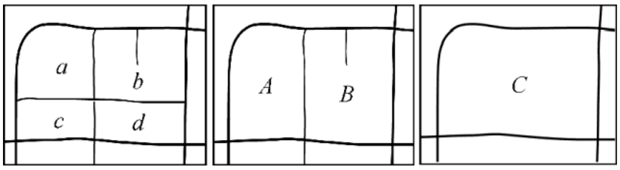

Figure 1. The classification sample of road meshes.

In order to ensure that the composition of the road mesh conforms to people's cognitive habits, the following principles must be followed in the composition[21]:

(1) The boundary of the road mesh is composed of vertices and edges. The edges actually correspond to a part (road segment) of a road (stroke), and the vertices are the intersections of different roads.

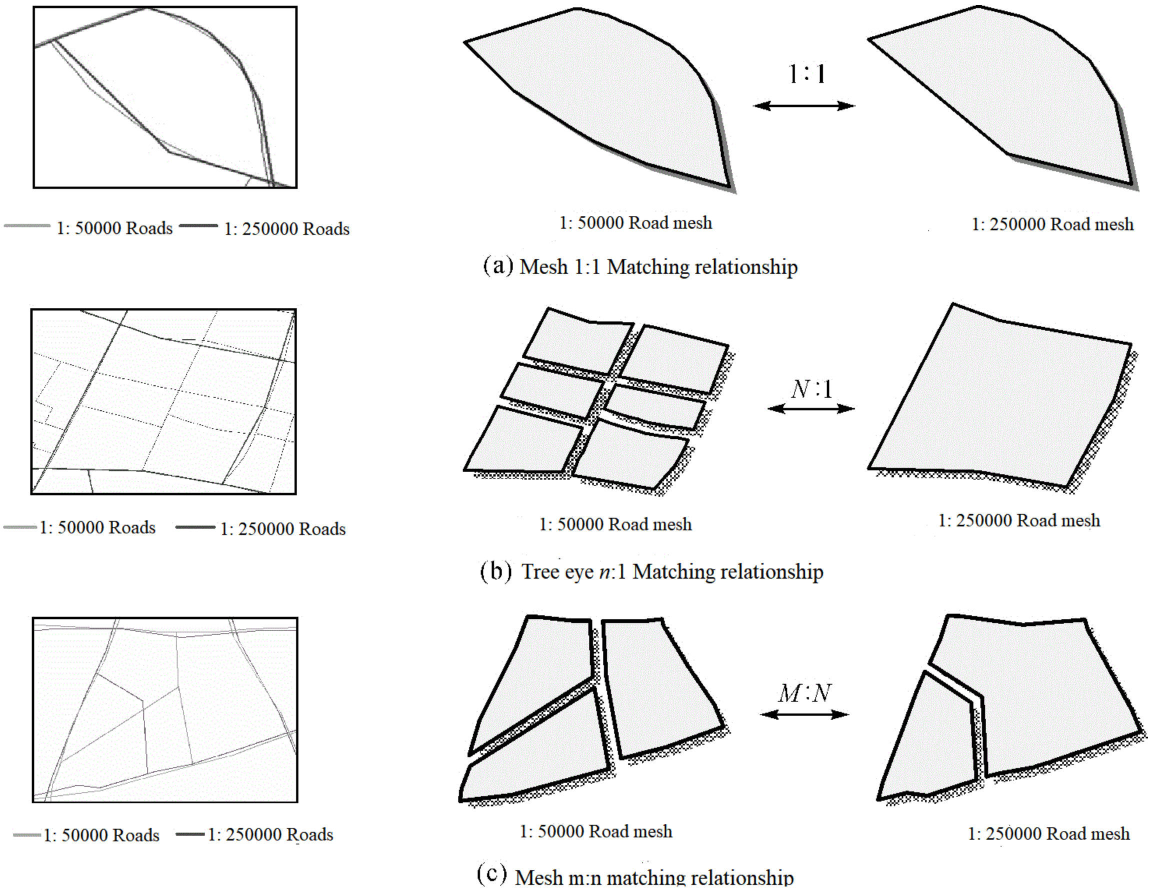

Figure 2. Matching relationships of road networks meshes of different scales in the same area.

(2) The grade of the compound road mesh boundary road cannot be lower than that of its internal mesh boundary road.

The grade of road mesh boundary road is determined by the attribute grade, structural importance and length of the road itself. For specific judgment methods refer Xu, Liu, Zhang, *et al.*[22].

2.2 Corresponding relationship of multi-scale road mesh

There are roads with the same name in the small-scale road network data and large-scale road network data of the same region. These roads have a high level in the large-scale road network data, and they constitute the "skeleton" network of the large-scale road network. The small-scale road network divides the spatial area into several larger mesh areas. The large-scale roads often further subdivide the areas corresponding to these large-scale road meshes, resulting in smaller meshes. Obviously, these smaller meshes are included in the large meshes of the small-scale road network, that is, the small meshes of the large-scale are constrained by the small-scale large meshes, which is the ideological basis of the matching method in this paper. **Figure 2** shows the road data of 1:50,000 and 1:250,000 in a certain area, reflecting the possible correspondence between the road meshes of large and small scale data.

For the road network data in the same area, the large-scale road further divides the internal space of the small-scale road mesh into several smaller meshes, so that the matching relationship between the large-scale and small-scale road meshes with the same name is N:1 (N > 1). It is obvious that N:1 matching is the main in the multi-scale mesh matching relationship. In addition, there are also a small number of M:N (M > 1, N > 1) and 1:1 matching relationships.

2.3 Basic ideas

Due to the high density of roads in large-scale data and the location error, the roads in small-scale data are easy to be mismatched with the roads near the entity roads with the same name. Using road mesh for matching can highlight the importance of road structure and weaken the impact of location error on matching. And the larger the road mesh is, the more tolerant it is to fault errors Its basic idea is to build a road mesh by establishing the topological relationship between roads. The road mesh divides the whole road network into different road subsets. First, the road mesh matching is used to realize the matching of the mesh boundary roads, and then the matching of the roads inside the mesh is implemented. This not only reduces the scope of the matching search, but also increases the correlation of the matching roads, which is convenient for the fast and accurate search of the matching road objects.

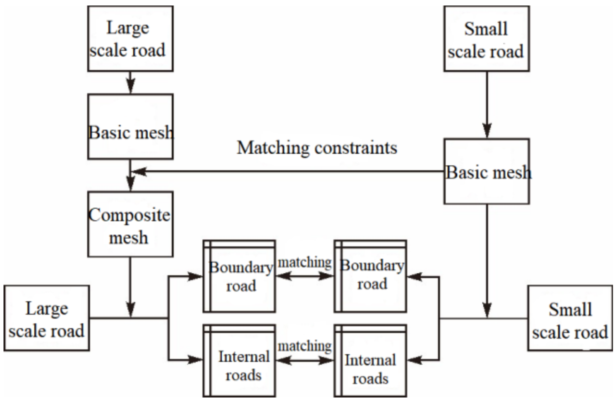

Figure 3. Matching of multi-scale road networks.

The N:1 and M:N matching relationship between large-scale road mesh and small-scale road mesh reflects the N:1 and M:N matching relationship between mesh boundary sections. In the matching relationship of road elements, the N:1 and M:N matching relationship is much more complex than the 1:1 relationship. The ideal method is to transform the N:1 and M:N matching relationship between roads into 1:1 matching relationship, so as to improve the matching efficiency and accuracy. In fact, the roads in the small-scale data and the entity roads with the same name in the large-scale data are often skeleton roads in the large-scale road network. The "1:1" matching relationship road mesh or composite mesh is formed by extracting and combining with the small-scale mesh from the large-scale road mesh, and the "1:1" matching of the corresponding boundary roads between the matching meshes is realized according to the "1:1" matching relationship between the meshes. Then, according to the consistency principle, the internal roads of the mesh are merged, and then the internal roads of the mesh are matched.

3. Implementation method of multi-scale road matching

3.1 Extract composite mesh according to matching relationship

3.1.1 Extract the composite mesh of *N*:1 and 1:1 matching relationship

The key of using road mesh to realize multi-scale road matching is to extract the road mesh (or composite road mesh) that constitutes the matching relationship from the large and small-scale road network data respectively. The extraction steps of road mesh with N:1 ($N > 1$) and 1:1 matching relationship between large-scale road network and small-scale road network are as follows:

(1) Calculate the overlap rate of large-scale basic road mesh and small-scale mesh. The overlap rate of large-scale basic mesh and small-scale mesh largely determines which mesh is constrained by small-scale data when extracting composite mesh, which affects the accuracy of composite mesh extraction. The calculation formula of overlap rate is

$$R = \frac{\mathrm{Area}_{\mathrm{overlap}}}{\mathrm{Area}_{\mathrm{large}}} \times 100\% \quad (1)$$

Where, $\mathrm{Area}_{\mathrm{overlap}}$ is the area of the intersection of large-scale basic road mesh and small-scale mesh; $\mathrm{Area}_{\mathrm{large}}$ refers to the mesh area of large-scale road. Set the threshold R_0. When $R \geq R_0$, the small-scale road mesh is a constraint mesh.

(2) Search all meshes constrained by the same small-scale mesh in the large-scale basic road network and put them into the same candidate set.

(3) Combine the meshes in the same candidate set and extract the initial composite mesh, as shown in **Figure 4(c)**.

There is a position deviation between the roads with the same name in different scale data, which leads to the deviation in the extraction of composite road mesh, which shows that the large-scale road mesh is not in the corresponding small-scale mesh area (with a low overlap rate), or even in the adjacent mesh area. In order to extract the composite mesh more accurately, it is necessary to evaluate and correct the extracted initial composite mesh, identify the missing mesh and merge it with the initial composite mesh, and remove the erroneously added mesh from the initial composite mesh to get the correct extraction result.

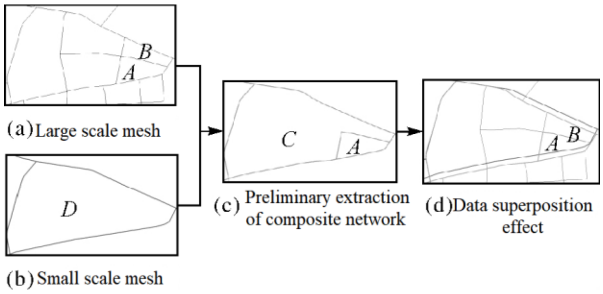

Figure 4. Extraction of composite meshes in the first step.

Take **Figure 4** as an example to illustrate the basic process of initial composite mesh correction. In **Figure 4**, C is the composite mesh preliminarily extracted under the constraint of mesh D. mesh a was not selected during preliminary extraction because the overlap rate was lower than the threshold. B is the large-scale mesh of C correctly extracted, adjacent to a and with the smallest area. Analyze a to determine whether to merge with the initial composite mesh C to generate a new composite mesh. The determination process is as follows:

(1) Search the mesh adjacent to a in the initial composite mesh C, and select mesh B with the highest overlap rate and the smallest area as a candidate. If there is a conflict between the maximum overlap rate and the minimum area, it is required to give priority to the overlap rate index.

(2) Merge a with candidate B, and calculate the overall overlap rate after merging according to formula (2)

$$R_{\mathrm{AB}} = \frac{\mathrm{Area}_{\mathrm{overlap}\_A} + \mathrm{Area}_{\mathrm{overlap}\_B}}{\mathrm{Area}_A + \mathrm{Area}_B} \times 100\% \quad (2)$$

Where R_{AB} is the overlap rate of *AB* as a whole, $\mathrm{Area}_{\mathrm{overlap\_A}}$ and $\mathrm{Area}_{\mathrm{overlap\_B}}$ is the overlapping area of *A*, *B* and small-scale mesh respectively, and Area_A and Area_B are the area of mesh *A* and B respectively.

(3) Compare R_{AB} with R_0. If $R_{\mathrm{AB}} \geq R_0$, mesh C is a candidate for merging with mesh *A*. Make the same determination for the next composite mesh adjacent to a until all composite meshes adjacent to a are determined, and select the composite mesh

with the highest overlap rate from all candidates of mesh *A* to merge with mesh *A*. If a composite mesh that can be merged cannot be found according to the above method, mesh a remains independent.

In addition to re adding the missing road mesh above, it is also necessary to remove the mesh added incorrectly, as shown in **Figure 5**.

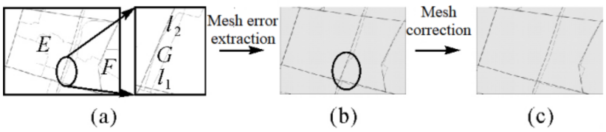

Figure 5. Wrong extraction of meshes and correction.

According to cognitive judgment, the basic mesh *G* in the large-scale road mesh corresponds to the small-scale road mesh *E* and becomes a candidate for the composite mesh generated under the constraint of mesh *E*. However, according to the overlap rate, mesh *G* corresponds to the adjacent mesh *F* of mesh *E* and becomes a candidate for the composite mesh constrained by mesh *F*. This error needs to be corrected. According to the definition of road mesh, the grade of the boundary road of the road mesh should be higher than that of the internal road, and the mismatched small mesh should be eliminated accordingly. Compared the grade of the boundary road of the initial composite mesh with that of the internal mesh, as shown in **Figure 5(a)**, determining the attribute grade of the boundary roads l_1 and l_2 of the basic mesh *G*. l_1 is a highway and l_2 is a substandard highway. Obviously, the grade of l_1 is higher than l_2, indicating that the initial composite mesh *F* obtained above is problematic. Mesh *G* should be removed from composite mesh *F* and incorporated into mesh *E* to complete the correction of composite mesh.

After the above steps, the matching relationship of road meshes with different scales is completed. Finally, it is necessary to judge their similarity in size to avoid false matching. The size similarity is calculated as

$$Y = \frac{\text{Area}_{\text{complex}}}{\text{Area}_{\text{small}}} \times 100\% \quad (3)$$

Where, *Y* is the similarity index, and the threshold value of Y is set as $\varepsilon_0 \leqslant Y \leqslant 1$; $\text{Area}_{\text{complex}}$ is the initial composite mesh area and $\text{Area}_{\text{small}}$ is the matching small-scale mesh area. When *Y* is greater than or, it is finally confirmed that the two match.

Through the constraint of small-scale road mesh, the corresponding composite mesh of large-scale mesh is extracted, and the matching of roads is realized through the matching relationship between meshes. This method avoids the interference of irrelevant road data in large-scale road data to the matching process, simplifies the matching process, and improves the efficiency and accuracy of matching. The process of extracting composite mesh is shown in **Figure 7**.

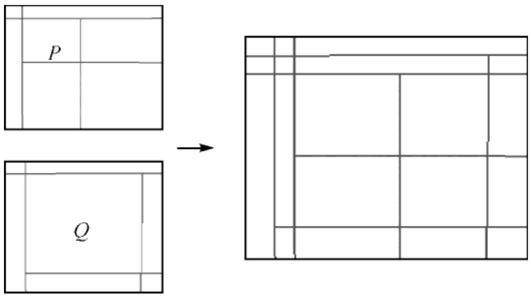

Figure 6. Fake matching relationship of meshes.

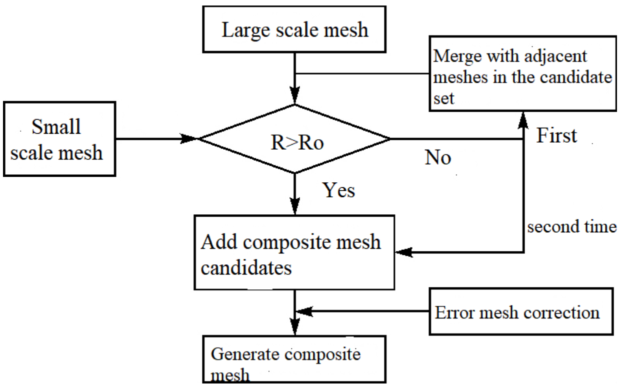

Figure 7. Extraction of composite meshes.

3.1.2 Extract the composite mesh of *M*:*N* matching relationship

In the multi-scale mesh matching relationship, after processing the 1:1 and *N*:1 matching relationships, there may be unmatched meshes left, which belong to the *M:N* matching relationship. The mesh with *M*:*N* matching relationship presents the characteristics of "community" in space, that is, several unmatched meshes tend to gather together, and the mesh *M:N* matching relationship is recognized by merging adjacent meshes in the community area.

The mesh aggregation areas with community characteristics are treated area by area, and the treatment process is as follows:

(1) Merge a mesh aggregation area as a whole into a composite mesh, then match the combined composite mesh with the size scale, and then determine whether the pair of composite meshes match according to the matching conditions in the previous section. If they match, proceed to the processing of the next mesh aggregation area until the matching of all unmatched meshes is completed, and the matching process stops; if not, go to step (1).

(2) Arbitrarily select two adjacent meshes in the small scale to merge into a composite mesh, merge the mesh intersecting with it in the large scale and the overlap rate reaches the threshold R_0 into a composite mesh, and determine whether the two match. If they match, use the same method to match the remaining meshes; if the composite mesh obtained by merging any two remaining meshes cannot be matched, go to step (3).

(3) Randomly select three adjacent meshes in the small scale to merge into a composite mesh, merge the meshes intersecting with it in the large scale and the overlap rate reaches the threshold R_0 into a composite mesh, and determine whether the two match. If they match, use the same method to match the remaining meshes; if the composite mesh obtained by merging any of the remaining three meshes cannot be matched, increase the adjacent meshes one by one and repeat step (3) until the matching is finally completed. Then proceed to the next mesh aggregation area until all mesh matching decisions are completed.

3.2 Road classification processing using road mesh matching

After mesh matching is completed, classification matching is carried out according to the topological relationship between roads and meshes. The roads to be matched are divided into mesh boundary roads and mesh internal roads according to categories. After topological processing, the original road data will be segmented at the intersection of roads to form nodes and arcs. Since the matching relationship between road meshes is not only 1:1, but also N:1 and M:N, it is necessary to merge the boundary road arc and internal road arc in the composite mesh, and merge the arc into stroke according to the goodcontinuity principle in Gestalt visual perception[23,24]. In order to improve the efficiency of road matching, it is necessary to establish the topological mapping relationship between composite mesh and mesh road. As shown in **Figure 8**, after mesh matching and recognition, a certain scale of road network is extracted to obtain several composite meshes. The topological mapping relationship between the composite mesh and its boundary roads and interiors is shown in **Table 1**.

Figure 8. The road network and composite meshes by matching.

Table 1. Mapping relationship between composite meshes and road

Composite mesh	Boundary road of composite mesh	Internal road of composite mesh
A	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	11, 12, 13, 14, 15, 16, 17, 18, 19
B	7, 8, 26, 28, 30, 31	29, 32, 33
C	5, 6, 22, 23, 24, 25, 26	20, 21, 27

According to the mesh matching results and the topological mapping relationship between roads and meshes, the mesh of the matching road can be quickly determined, so as to greatly reduce the scope of matching search and improve the efficiency and accuracy of road matching.

3.3 Realization of road matching

Establishing a matching relationship is the process of mapping matching data to reference data. This paper uses mesh matching constraints to realize road matching. The process is as follows: first, mesh matching recognition is carried out on large-scale and small-scale road meshes to obtain the matching road mesh (composite road mesh), then the boundary roads of the identified matching mesh are matched, and finally the internal roads of the mesh are matched. First, matching the mesh boundary roads, for the two road meshes that have been matched, it is easy to determine the matching of the mesh boundary roads. Taking a small scale that has matched an edge (road segment) of the road mesh, its matching object must be an edge (road segment) of the corresponding large-scale matching road mesh, avoiding a large-scale search. Once the matching object of one edge is determined, the matching objects of other edges can be derived according to the connection order of mesh edges.

Due to the mesh matching constraints, the matching judgment of mesh boundary roads can be achieved without complex similarity calculation. This paper uses the Hausdorff distance[25] to match the boundary roads of the matched road mesh, and selects the road with the smallest distance as the matching object.

Hausdorff distance was originally used to measure the distance between point sets. If there are two point $A=\{a_1,a_2,\cdots,a_m\}$ sets $B=\{b_1,b_2,\cdots,b_n\}$ and, the Hausdorff distance between point sets a and B is defined as

$$d_H(A,B)=\max(d_h(A,B),d_h(B,A)) \quad (4)$$

Where:

$$d_h(A,B)=\max_{a\in A}\min_{b\in B}\|a-b\| \quad (5)$$

$$d_h(B,A)=\max_{b\in B}\min_{a\in A}\|b-a\| \quad (6)$$

$d_h(A,B)$ represents the maximum VALUE of the minimum distance from each point IN point set a to point set B.

Line elements can be regarded as a set of ordered points, so the Hausdorff distance CAN be used to measure the distance between line elements. It reflects the overall distance between line elements, which is more reasonable than simply using European distance, and is often used for matching judgment between line elements.

There are two types of internal roads that have been matched with mesh, one is the road that can form mesh segmentation, and the other is the road that does not form mesh segmentation. The first type of internal road has no matching object and will not be processed. The second type of road is mainly some suspended roads. For this type of road matching, the corresponding matching mesh can be searched for possible matching roads.

4. Test and analysis

4.1 Test data

In this paper, 1:250,000 and 1:50,000 partial road data of Ningbo are selected for matching test. First, the road network data of two different scales are projected, and the coordinates are uniformly transformed, and then superimposed and displayed, as shown in **Figure 9**. Among them, the 1:250,000 road network has a data volume of 80 Kb and 382 objects; 1:50,000 road network, 594 KB data volume, 1,588 objects.

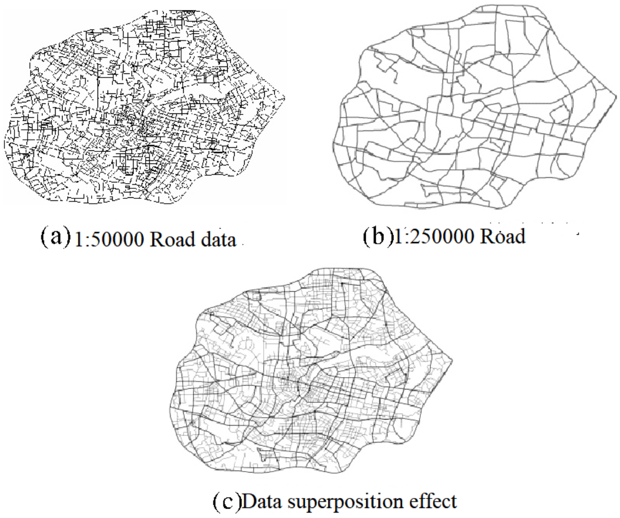

Figure 9. The multi-scale road networks data.

4.2 Matching test results

The meshes of 1:50,000 and 1:250,000 road network data are matched and identified, so as to extract the road meshes that constitute the matching relationship in the two data sets. According to formula (1), the matching relationship between multi-scale meshes is preliminarily established, and the meshes with matching relationship between the large-scale mesh and the same small-scale mesh are combined to generate a preliminary composite mesh. After many tests, due to the small position error of the test data, it is more appropriate to set the overlap rate $R_0 = 0.9$ after the test. The generated results are shown in the preliminary composite mesh in **Figure 10**, and the red area is the mesh to be further processed.

The number of meshes in the 1:50,000 target data is 1,473. First, rough extraction of composite meshes is carried out, most of the large-scale meshes are processed, and the preliminary composite meshes are obtained. The remained 79 meshes do not meet the threshold conditions in the process of preliminary extraction of composite meshes, and further judgment and processing are required, as shown in **Figure 10(c)**. The determination results of this part of mesh are shown in **Table 2**.

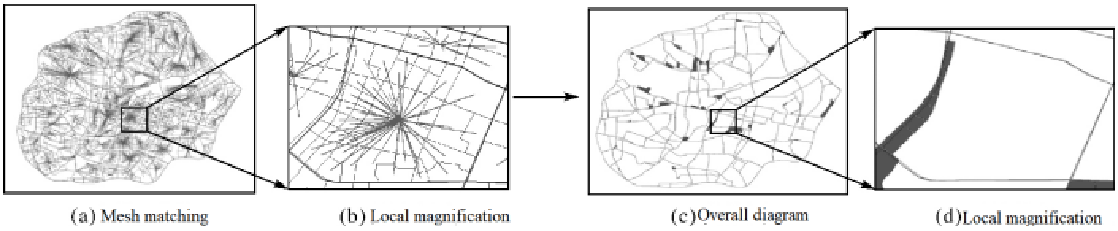

Figure 10. Preliminary extraction of composite meshes.

Table 2. Solving the problem of mesh's merging

Mesh ID to be processed	Matching probability with intersecting small-scale mesh/(%)	Candidate mesh ID	Combined overall matching probability/(%)	Whether to merge with adjacent composite mesh
54	57.72, 42.28	90, 80	98.74, 96.99	yes
⋮				
434	65.43, 34.57	386, 392	69.56, 59.07	no
⋮				
713	72.99, 27.01	724, 658	86, 67.29	no
⋮				
1,250	71.12, 28.88	1,242, 1,264	76.31, 37.33	no
⋮				
1,443	80.44, 19.56	1,434, 1,455	92.57, 35.48	yes
⋮				

After further extraction, 75 of the 79 mesh to be processed were judged to meet the merging conditions, and were merged with the adjacent optimal composite mesh. Then, according to the similarity index y, the threshold was set to $0.9 \le Y \le 1.1$, and 7 meshes were removed from the matching relationship, and finally 11 unmatched meshes were obtained, as shown in **Figure 11(a)**. On this basis, *M:N* matching is performed in the remained unmatched mesh.

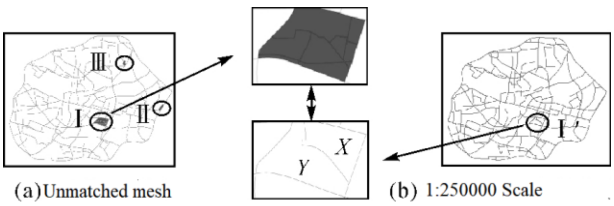

Figure 11. An example of many-to-many matching of meshes under different scales.

In the extracted composite mesh, the unmatched mesh at I forms an aggregation area corresponds to the unmatched mesh *X* and *Y* at I' in the small-scale mesh. According to the matching idea in section 3.1.2, the composite mesh composed of unmatched mesh *X* and *Y* at I' in the small-scale ruler forms a 1:1 match with the composite mesh composed of all meshes at I in the large-scale ruler, which is essentially a 9:2 matching relationship between unmatched meshes. So far, the matching between all meshes in road mesh data of different scales has been completed.

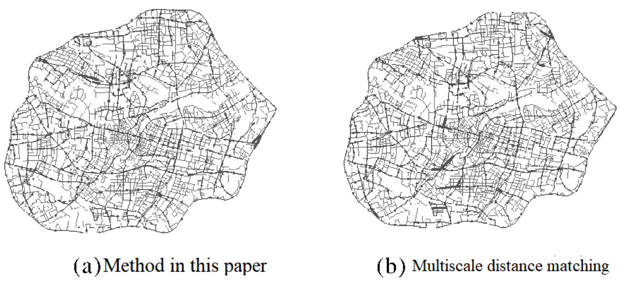

Figure 12. Results of multi-scale match of road in two different methods.

The large-scale composite road mesh extracted by mesh matching recognition constitutes the skeleton mesh of the large-scale road network. The boundary roads and internal roads of the extracted matching mesh are merged according to the stroke consistency principle, and the topological mapping relationship between the road mesh and the road is established. After processing, the *N:1* or *M:N* matching relationship between the original matching mesh boundary roads becomes a "1:1" matching relationship, which reduces the number of objects to be matched, greatly simplifies the difficulty of matching, and improves the accuracy of matching. Using Chen Yumin's distance matching algorithm of multi-scale road network[17] for the same data, the matching results of the test data are shown in **Figure 12**, and the test statistical results are shown in **Table 3**.

Table 3. Results of the two different methods

Method	Number of roads		Number of matches	Number of correct matches	Number of wrong matches	Unmatched number	Match rate/(%)	Matching accuracy/(%)
	Reference data	Target data						
Method in this paper	382	1,588	367	364	3	15	96.07	99.18
Multiscale distance matching algorithm	382	1,588	343	328	15	39	89.79	95.63

4.3 Comparative analysis

According to the test results, when there are short lines in the data, the multi-scale distance matching algorithm will form a wrong match with the roads near the short lines in the matching process. The reason for this phenomenon is the defect of the algorithm itself. When the line elements are short, the number of points as a point set is very small, causing most or even all points to fall into the buffer of the adjacent long line elements, resulting in a wrong match. In this method, because the shorter line elements are also the boundary elements of the mesh, it is only necessary to consider the boundary elements of the mesh corresponding to the mesh when matching, which can effectively avoid the wrong matching of these shorter path route elements, as shown in **Figure 13**.

For the case of large difference of route elements with the same name, the multi-scale distance matching algorithm also has shortcomings, and the matching cannot be completed. While the method in this paper does not rely on morphological similarity very much, so it has certain advantages in matching. As shown in **Figure 14**, the roads with the same name with certain morphological differences cannot be matched by using the multi-scale distance matching method, while the method in this paper can easily match the two by using the corresponding relationship of the mesh where the elements with the same name are located.

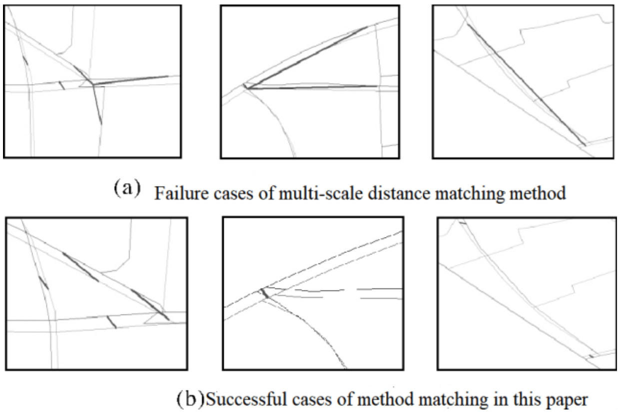

Figure 13. The contrast experiment of the two matching methods.

(a) Multiscale distance matching (b) Method in this paper

Figure 14. The contrast experiment of the two matching methods.

Through the comparison results of experiments, it can be concluded that the algorithm proposed in this paper has certain advantages over the multi-scale distance matching algorithm in terms of matching rate and accuracy, mainly due to the following two points. Firstly, this method uses mesh to constrain the road, and through the matching of mesh, the fuzzy correspondence of the road is transformed into the clear correspondence of the road of the matching mesh, which reduces the search scope of the matching road. At the same time, it reduces the dependence of the road itself on location and shape similarity, which has better practical significance in multi-scale matching. Secondly, the idea of classification matching divides roads into mesh boundary roads and internal roads, so that the matching is limited to the roads of the same category, which reduces the interference and improves the accuracy of matching.

5. Conclusion

The matching of road networks is often handled by geometric matching. In the matching of multi-scale road networks, if geometric features are directly used for matching without extraction, the match is often very poor. The reason is that there are differences in the geometric shape, topological relationship and attribute information of roads at different scales, which cannot ensure that the data has a stable matching basis. At the same time, many other road data in large-scale data will greatly interfere with the matching process, resulting in increased uncertainty of matching. This method extracts the main road matching candidate set through mesh matching, eliminates irrelevant road elements from the matching process, and reduces the dependence on road geometry during matching. Compared with traditional matching methods, it improves the matching accuracy.

The extraction of mesh matching relationship is a key of this algorithm. If the position deviation is large, it will have a negative impact on the matching results. In view of this situation, it can be considered to firstly select a small number of high-level skeleton roads in the small-scale data to form a larger road mesh. The large mesh has a stronger ability to resist the position error. First, Matching relationships are firstly extracted for these large meshes. After the matching is completed, use the matching results to correct the position, which can greatly reduce the position error of the data and improve the accuracy of the subsequent extraction of smaller road mesh matching relationship.

Conflict of interest

The authors declare that they have no conflict of interest.

Reference

1. Cheng J. Study on the integrative organization and representation method for geographical entity in different scales (in Chinese) [MSc thesis]. Hangzhou: Zhejiang University; 2011.
2. Wang Y, Li X, Gong H. On multi-scale representations of geographic features (in Chinese). Science in China Series E: Technological Sciences 2006; 49(S2): 39–47.
3. Balley S, Parent C, Spaccapietra S. Modelling geographic data with multiple representations. International Journal of Geographical Information Science 2004; 18(4): 327–352.
4. Ai T, Cheng J. Key issues of multi-scale representation of spatial data (in Chinese). Geomatics and Information Science of Wuhan University 2005; 30(5): 377–382.
5. Zhang Q, Wu F, Qian H, *et al*. Milestone scales oriented spatial data multi-representation techniques (in Chinese). Journal of Geomatics Science and Technology 2011; 28(5): 383–386.
6. Wei H. The research and application of multiscale geographic database in GIS (in Chinese). Journal of Institute of Surveying and Mapping 2000; 17(2): 134–137.
7. Wu F, Zhang Q, Gong X, *et al*. Matching and classification model for multi-scale transformation and representation of spatial data (in Chinese). Journal of Geomatics Science and Technology 2014; 31(4): 331–335.
8. Xu F, Deng M, Zhao B, *et al*. A detailed investigation on the methods of object matching (in Chinese). Journal of Geo-Information Science 2009; 11(5): 657–663.
9. Chen J, Qian H, Wang X, *et al*. Improving the matching rate of line feature by using dynamic simplification (in Chinese). Acta Geodaetica et Cartographica Sinica 2016; 45(4): 486–493.
10. Walter V, Fritsh D. Matching spatial data sets: a statistical approach. International Journal of Geographical Information Science 1999; 13(5): 445–473.
11. Zhai R. Research on automated matching methods for multi-scale vector spatial data based on global consistency evaluation (in Chinese) [PhD thesis]. Zhengzhou: Information Engineering University; 2011.
12. Saalfeld A. Conflation automated map compilation. International Journal of Geographical Information Systems 1988; 2(3): 217–218.
13. Zhang M, Shi W, Meng L (editors). A generic matching algorithm for line networks of different resolutions. Proceedings of the 8th ICA Workshop on Generalisation and Multiple Representation; 2005 July 7–8; A Coruna. A Coruna: ICC; 2005. p. 10.
14. Volz S (eiditor). An iterative approach for matching multiple representations of street data. In: Hampe M,

Sester M, Harrie L (editors). Multiple representation and interoperability of spatial data. Session 6: Matching. Hanover, Germany: ISPRS; 2006. 101-110.
15. Goesseln GV (editor). A matching approach for the integration, change detection and adaptation of heterogeneous vector data sets; 2005 Jul 9-16; A Coru ña. XXII International Cartography Conference. A Coru ña, Spain: International Cartographic Association; 2005.
16. Liu H, Qian H, Wang X, *et al*. Road networks global matching method using analytical hierarchy process (in Chinese). Geomatics and Information Science of Wuhan University 2015; 40(5): 644–651.
17. Chen Y, Gong J, Shi W. A distance-based matching algorithm for multi-scale road networks (in Chinese). Acta Geodaetica et Cartographica Sinica 2007; 36(1): 84–90.
18. Zhao D, Sheng Y. Research on automatic matching of vector road networks based on global optimization (in Chinese). Acta Geodaetica et Cartographica Sinica 2010; 39(4): 416–421.
19. Luan X, Yang B, Li Q. Pattern-based node matching approach for road networks (in Chinese). Acta Geodaetica et Cartographica Sinica 2013; 42(4): 608–614.
20. Zhao H. Extracting and application on the classification of urban roads mesh tree (in Chinese) [MSc thesis]. Beijing: Beijing University of Civil Engineering and Architecture; 2014.
21. Zhai R, Wu F, Huang B, et al. A method for recognition and representation of areal hierarchy of urban road networks (in Chinese). Journal of Geomatics Science and Technology 2014; 31(4): 413–418.
22. Xu Z, Liu C, Zhang H, et al. Road selection based on evaluation of stroke network functionality (in Chinese). Acta Geodaetica et Cartographica Sinica 2012; 41(5): 769–776.
23. Thomson RC, Richardson DE (editors). The “good continuation” principle of perceptual organization applied to the generalization of road networks. Proceedings of the 19th International Cartographic Conference; 1999 Aug 14-21; Ottawa. Singapore: ICA; 1999.
24. Thomson RC, Brooks R (editors). Efficient generalization and abstraction of network data using perceptual grouping. Proceedings of the 5th International Conference on GeoComputation; 2000 Aug 23-25; Manchester. London: University of Greenwich; 2000.
25. Huttenlocher DP, Klandermanga GA, Rucklidge WJ. Comparing images using the Hausdorff distance. IEEE Transactions on Pattern Analysis and Machine Intelligence 1993; 15(9): 850–863.