Research on Intelligent Scale Pedestrian Navigation Map Based on Rough Set Rules

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Abstract. With the popularity of smart phones, pedestrian navigation maps based on smart phones are widely used, but the readability of pedestrian navigation map is not satisfactory. In this paper, an intelligent scale pedestrian navigation map model based rules is proposed. The realization process of intelligent scale navigation map includes the measurement of the spatial distribution of road network in adjacent space and peripheral space, the construction of map scale decision table based on rough set, the extraction of rules and the matching of rules. Finally, the experimental results prove that the intelligent scale navigation map based on rules is feasible, and the effect is better than that of static scale navigation map.

1. Introduction

With the popularity of smart phones, mobile map has become an important auxiliary tool in people's work and life, such as tourism guidance, vehicle navigation. From the desktop to smart phone mobile map, visualization and application environment of smart phone map has changed significantly; map user scope is also broader. Therefore, smart phone mobile map cannot simply copy the cartographic model of desktop map [1]. It is necessary to study the special needs of the user groups in the new environment for the smart phone mobile map. In mobile environment, whether tourism guidance or vehicle navigation, the most important demand of users is intelligent map reading with minimum map operation or intervention. Obviously, reasonable map scale selection is very important to realize intelligent map reading. Through analysis, the factors that affect the user's selection of map scale include the cognitive environment and the spatial distribution of the geographical objects in the cognitive space. If the cognitive environment is determined (urban pedestrian navigation in this paper), the selection of map scale is mainly influenced by the spatial distribution of geographical objects. For urban pedestrian navigation map, the most important geographic object is the road network and POIs. So, if we can establish the correspondence relation between urban road network distribution and the scale of pedestrian navigation map, we can achieve intelligent scale changes in navigation map. Considering the inaccurate and uncertain characteristics of map scale selection, and combining the advantages of rough set theory in dealing with these problems, this paper proposes an intelligent scale pedestrian navigation map model based on rough set rules.

The following of the paper is organized as follows. Section 2 introduces the intelligent scale principle and realization process. Section 3 proposes the measurement method of road network’s spatial distribution based on position. Section 4 introduces the method of rule extraction. Section 5
introduces the rule matching method. Section 6 describes the experiment and results. Section 7 concludes the paper.

2. Intelligent Scale Principle and Process

2.1 Basic thought and principle

The navigation map scale which user selects in different positions is influenced by many factors. The main factors include application requirements (goals, motivations and planning), individual factors (physiology, psychology, culture and state), cognitive environment (moving speed) [2] and the map load capacity and other factors [3]. Under the premise of specific demand factors (such as finding the way) and approximate cognitive environment, the density of geographical elements will play a key role in selecting map scale of a specific pedestrian when browsing map outdoor.

Through the analysis, in the public service oriented map, the most important geographic element is the road network in cities and rural areas, which is also the most important information for users to make spatial cognition and space decisions. As for the map application for mountainous areas and special topics, the terrain elements or thematic elements (such as water resources elements) can be used as the main factors influencing the map scale selection, but it is not the content of this research. So the inspiration comes, which establishes the relationship between spatial distribution of road network and map scales by collecting user's map operation data in different positions, and then selects map scale, named intelligent map scale according this relation. In order to achieve this goal, two outstanding problems must be solved. One is the evaluation of road network in spatial distribution density, and the other is how to establish the rules between the road distribution and map scale. A Delaunay triangulation network method is used to evaluate road network’s spatial distribution density. In view of the complexity, vagueness and uncertainty of map cognition process and mechanism [4], Rough Set method is used to set up the relationship model of specific pedestrian between spatial distribution of road network and suitable map scales. Figure 1 is the principle and process realizing intelligent scale.

![Figure 1. The principle and process realizing intelligent scale](image)

2.2 Rough Set Theory

2.2.1 Information system and decision table. In Rough Set theory, the information system can be represented as a four tuple of \( S = \langle U, R, V, f \rangle \), in which \( U \) is a nonempty finite set of research objects, named domain. \( R \) is a set of nonempty finite attributes, \( V = \bigcup_{r \in R} V_r \) is the set of attribute values, and \( V_r \) represents the value range of attribute \( r \in R \). \( f : U \times R \rightarrow V \) is an information function referring the attribute value range of object \( x \), that is if \( \forall x \in U, r \in R \), existing \( f(x, r) \in V_r \). Decision table is a
special and important knowledge representation system, which means when certain conditions are met, how should a decision (behavior, operation, control) be made.

2.2.2 Upper and lower approximate set. The indistinguishable relation is used to express the specific objects which cannot be distinguished in the information system. Its essence is an equivalent relationship. Suppose \( S \subsetneq U, \{R, V, f\} \) is an information system, and \( \forall B \subseteq R \), then its corresponding undistinguishable relationship can be defined by formula (1) [5, 6].

\[
\text{IND}(B) = \{(x, y) \in U \times U \mid \forall r \in B, f(x, r) = f(y, r)\}
\]  

(1)

If \((x, y) \in \text{IND}(B)\), the subset \( B \) of the object \( x \) and \( y \) on the attribute set \( R \) is an undistinguishable relation. Equivalent partition \( U / \text{IND}(B) \) can be obtained according to indistinguishable relation \( \text{IND}(B) \), and \( U / \text{IND}(B) \) is named as basic set of group \( B \). If \( X \subseteq U \), when \( X \) can be accurately expressed by the attribute subset \( B \), then \( X \) can be defined by \( B \). Otherwise, \( X \) cannot be defined in \( B \). The \( B \) can define a group set called \( B \)'s precise set. Otherwise, the set is named as \( B \)'s non-precise set or \( B \)'s Rough Set. The uncertainty of rough set can be expressed with upper approximation and lower approximation. In the system \( S \subsetneq U, \{R, V, f\} \), if \( X \subseteq U \) and \( B \) is the indistinguishable relation, \( X \)'s lower approximation set and lower approximation set can be defined by formula (2) and (3).

\[
\overline{B}(X) = \cup\{Y \mid Y \in U \mid \text{IND}(B) \wedge Y \cap X \neq \emptyset\}
\]  

(2)

\[
\underline{B}(X) = \cup\{Y \mid Y \in U \mid \text{IND}(B) \wedge Y \subseteq X\}
\]  

(3)

2.2.3 Discretization. When the decision table is processed with rough set theory, the value of the decision table needs to be expressed as discrete values (e.g. integer type, string type, and enumerated type) [7]. There are two main kinds of discrete methods. The first category is adopted directly from other disciplines without consideration to the special nature of Rough Set theory. Naturally, the discrete effect is not prominent. These methods include equal interval width, equal frequency intervals, naive scale algorithm, and semi naive scale algorithm. The other is to give full consideration to the special requirements of Rough Set theory, take the combination methods to solve discrete problems. The discretization algorithm of Boolean logic combining RS theory is a typical representative. Its advantages is obvious comparing with the former [7].

2.2.4 Knowledge reduction. Knowledge reduction is very important of rough set theory. The importance of knowledge in knowledge library is not the same, and even some knowledge is superfluous. Knowledge reduction is to remove irrelevant or unimportant knowledge and keep knowledge library classification ability without changing.

2.2.5 Decision rules and coordination. Decision rules can be expressed as \( A \rightarrow B \), there \( A \) is a conditional attribute value, and \( B \) is a decision attribute value. If any object \( x \in U \) and decision rule \( A \rightarrow B \) can be satisfied, the decision rule in decision table is named as coordination. Otherwise, the decision rule in decision table is incoordination [10]. The uncertainty of the decision rules can be expressed by the degree of confidence and coverage. Confidence degree can be calculated with formula (4) and the coverage degree can be calculated with formula (5). Among formulas, \( X = \{x \mid x \in U \wedge A_x\} \), \( Y = \{x \mid x \in U \wedge B_x\} \). \( A_x \) indicates that the condition attribute value of instance \( x \) satisfies \( A \), \( B_x \) indicates that decision attribute value of instance \( x \) satisfies \( B \). That is, the set \( X \) is an instance set which condition attribute value satisfies \( A \), and set \( Y \) is a set of instances which decision attribute value satisfies \( B \).

\[
\alpha = CF(A \rightarrow B) = \frac{|X \cap Y|}{|X|}
\]  

(4)
3. Measure Method of Road Network’s Spatial Distribution Based on Position

The density method and the nearest neighbor index method are widely used to evaluate the distribution of spatial objects [8]. However, density method is a statistical calculation of all the objects in a space, it cannot meet the needs of people's cognition of local space goals and their mutual relations.

When the number of point set is large, the nearest neighbor index method costs much time to find the nearest neighbor point, and it is difficult to define the criterion of spatial distribution type [9-11]. The measurement model based on neighborhood relation takes user's position and relation with surrounding objects into consideration, so it is more in line with user’s spatial cognitive habits [12, 13]. Meanwhile, the Delaunay Triangulation Network has the features of simple structure, the best shape of triangular net [14], and getting consistent result from any position of the net [15-17]. Therefore, the research adopts the Delaunay triangulation to present the neighborhood relation of the road network nodes and evaluate its distribution. The method computes adjacent space of current position timely based on Delaunay triangle network, and then compute the spatial distribution index \( C_1 \) of adjacent space road network, also the spatial distribution index \( C_2 \) of peripheral range road network. \( C_1 \) reflects the spatial distribution of roads around the user, which is the main factor that affects the selection of map scale. \( C_2 \) reflects the spatial distribution of user's peripheral road network, which can assist users in spatial cognition and path planning. The calculation steps of \( C_1 \) and \( C_2 \) are as follows:

First, the road network control nodes in the road network model are extracted, including the intersection of road sections, the end points and turning points of road sections.

Secondly, based on nodes, the Delaunay triangulation is established to determine the neighbor polygon composed by neighbor control nodes and user’s position [18]. Neighbor control node means that the node exits a direct triangular edge connecting with user’s position. Figure 2 is the illustration of control nodes and the Delaunay triangulation. Figure 3 is the neighbor polygon (i.e. the red solid polygon) corresponding user’s position.

Finally, the \( C_1 \) index is calculated by using the formula (6), i.e. the number of road network nodes per unit area in neighbor space. Where \( P_j \) is the number of neighbor polygon vertices, and \( A_j \) is the area corresponding to the neighbor polygon composed of the neighbor nodes. The \( C_2 \) index is calculated by using the formula (7), where \( P \) is the total number in the screen range, and \( A \) is the total area of the screen range.

\[
\beta = Cov(A \rightarrow B) = \frac{|X \cap Y|}{|Y|}
\]

\[
C_1 = \frac{P_j}{A_j}
\]

\[
C_2 = \frac{(P - P_j)}{(A - A_j)}
\]
4. The Method of Rule Extraction

Considering the cognitive characteristics of the pedestrian navigation map, we choose the road network level $L$, the neighbor spatial distribution index $C_1$ of road network, and the peripheral spatial distribution index $C_2$ of the road network as the conditional attribute, and take the user selection scale $S$ as the decision attribute. $C_1$ and $C_2$ are discretized based on Boolean algorithm and rough set method, and $S$ is discretized with equal frequency method. Then the corresponding rules can be extracted based on upper and lower approximate set calculation. Table 1 is the illustration of rules, which can be used to recommend suitable scale to users. Because different users have different spatial cognitive abilities and characteristics, each user's rules are extracted separately, which is only used by the user.

5. Rule Matching

In order to verify the effectiveness of intelligent scale map for pedestrian navigation, an experimental system based on Gaode map SDK has been developed with HUAWEI smart phone. Figure 4 is the main interface of the experimental system. Functions of the experimental system include road network nodes collection, Delaunay triangulation construction, user neighbor polygon calculation, map operational data collection, roads’ spatial distribution index $C_1$ and $C_2$ calculation, rule extraction, intelligent map scale navigation service and so on. Taking into account the needs of pedestrian navigation, the road network is divided into three grades, i.e. ring road, main road and general road. The collected data of road network control points cover about 20 km2 of urban area, and cover different kind of roads.

6. Experiments

6.1 Introduction of the experimental system

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6.2 Experiment data acquisition and rule extraction

The experiment lets user read map at different positions and set appropriate map scale. At the same time, related data are automatically recorded by the system. 10 users were selected to participate in the experiment. Table 1 is the part experimental data. In the research, rough set software Rosetta was used to extract the relationship rules between $C_1$, $C_2$, $L$ and the appropriate map scale. Table 2 shows part of rules.

**Table 1.** The Part Experimental Data.

| No. | C1   | C2   | L   | S     |
|-----|------|------|-----|-------|
| 1   | 831.32 | 196.96 | 1   | 3315.01 |
| 2   | 224.34 | 41.73  | 1   | 4771.58 |
| 3   | 267.75 | 58.93  | 1   | 6782.85 |
| ... | ...   | ...   | ... | ...   |
| 58  | 17.24  | 6.12   | 2   | 57904.22 |

**Table 2.** Part of Rules.

| No. | Rules                                                                 |
|-----|-----------------------------------------------------------------------|
| 1   | $C_1 \geq 804.92$ and $C_2 \geq 130.81$ and $L=1 \rightarrow S=5100$   |
| 2   | $320.11 \leq C_1 < 804.92$ and $11.26 \leq C_2 < 92.10$ and $L=1 \rightarrow S=9100$ |
| 3   | $76.69 \leq C_1 < 117.16$ and $97.46 \leq C_2 < 130.81$ and $L=1 \rightarrow S=13100$ |
| ... | ...                                                                   |
| 46  | $11.59 \leq C_1 < 17.60$ and $5.70 \leq C_2 < 7.32$ and $L=2 \rightarrow S=44000$ |
6.3 Application and evaluation
In order to implement smart scale map and test its effect, 10 groups of rule extracted from users were transplanted to the experimental system, then let 10 users read map again with his (her) own rules one by one. Naturally, intelligent map scale can be changed automatically according to the rules at different position. We selected 30 positions to compare the quality between intelligent map scale and static map scale. The experimental results showed that the intelligent map scale wins at 25 positions. Obviously, the readability of pedestrian navigation map has been significantly improved.

7. Conclusions
This paper proposed a method to extract decision rule between the spatial distribution of road network and intelligent map scale based on Rough Sets. Further, the rule can be used to recommend scale automatically in the process of pedestrian navigation. In order to evaluate the distribution of road network at different positions, neighbor distribution index and peripheral distribution index model based on Delaunay triangulation were established. The rule extraction and rule matching were introduced respectively. The experimental results showed that the intelligent scale of pedestrian navigation map is feasible, and its readability has been significantly improved.

8. Acknowledgments
This work was supported by the National Natural Science Foundation of China (No. 41671455 and No.40971238).

9. Reference
[1] Chen, J., Yan, C. D., Zhao, R. L., Zhao, X. S.: Voronoi Neighbor-Based Self-Adaptive Clipping Model for Mobile Maps (in Chinese). Acta Geodaetica et Cartographica Sinica. 38(2), 152-156 (2009)
[2] Wan, G., Gao, J., Liu, Y. Z.: Research on Cognitive Map Formation Based on Reading Experiments (in Chinese). J. Remote Sens. 12(2), 339-344 (2008)
[3] Zhong, Y. X.: A Metrical Research on Map Legibility (in Chinese). Journal of Wuhan Technology University of Surveying and Mapping. 19(04), 346-351 (1994)
[4] Pawlak, Z.: Rough Sets. International Journal of Computer and Infomation Science. 11(5), 341-356 (1982)
[5] Liang, J. Y., Li, D. Y.: The Uncertainty and Knowledge Acquisition in Information System (in Chinese). Science Press, Beijing, China (2005)
[6] Wang, G. Y.: Rough Sets and Knowledge Acquisition (in Chinese). Xi’an Jiaotong University Press, Xi’an, China, (2001)
[7] Qiu, S. S., Quan, G. R., Kong, L. C., Guo, M. Z.: A Rule Learning Algorithm on Continuous Attributes Space (in Chinese). Journal of Harbin Institute of Technology. 32(3), 42-47 (2000)
[8] Zhang, C., Yang, B. G.: Quantitative Geography Foundation (in Chinese). Higher Education Press, Beijing, China (1984)
[9] Yan, Q. W., Bian, Z. F., Wang, Z.: A Spatial Analysis on Patterns of Settlements Distribution in Xuzhou (in Chinese). Science of Surveying and Mapping. 34(5), 160-163 (2009)
[10] Liang, H. M., Zhao, J.: Application of Geographic Information System on Spatial Distribution Characteristics of Settlement (in Chinese). Journal of Northwest University (Natural Science). 37(02), 76-80 (2001)
[11] Liang, H. M., Zhao, J.: Study on The Spatial Distribution Characteristics of Settlement in Loess Plateau by GIS (in Chinese). Human Geography. 16(06), 81-83 (2001)
[12] Yan, C. D., Zhao, R. L., Chen, J., Zhao, X. S.: Neighborhood-based Adaptive Geovisualization on Mobile Map (in Chinese). Geomatics and Information Science of Wuhan University. 31(12), 1112-1115 (2006)
[13] Yan, C. D., Zhao, Y. K., Guo, W.: The Measurement and Application of Adjacent Area Based on Delaunay Triangulation (in Chinese). Geography and Geo-Information Science. 29(2), 125-126 (2013)
[14] Lingas, A.: The Greedy and Delaunay Triangulations Are Not Bad in The Average Case and Minimum Weight Triangulation of Multi-Connected Polygons in NP-complete. Inf. Process. Lett. 158(2), 25-31 (1986)

[15] Tsai, V. J. D.: Delaunay Triangulations in TIN Creation: An Overview and A Linear-Time Algorithm. Int. J. Geographical Information Systems. 7(6), 501-524 (1993)

[16] Wang, P., Liu, L. N., Pan, C. H.: Delaunay Triangulation Fast Creation and Topology Automatic Form in GIS (in Chinese). Journal of Geomatics. 26(04), 24-27 (2001)

[17] Peng, Y. P., Liu, W. X. Study on Delaunay Triangulation and Voronoi Diagram Application in GIS (in Chinese). Engineering of Surveying and Mapping. 11(03), 39-41 (2002)

[18] Du, X. C., Guo, Q. S.: Spatial Neighborhood Relation Reasoning Based on Delaunay Triangulation (in Chinese). Science of Surveying and Mapping. 29(6), 65-68 (2004)