Proceedings of the 3rd International Conference on Computing Innovation and Applied Physics
DOI: 10.54254/2753-8818/34/20241143

Road dynamic landscape design and simulation based on fuzzy clustering algorithm

Zounian Peng[1,3,4], Mengce Di[2,5], Dan Zhang[1,6], Qian Zhang[1,7], Yi Liu[1,8]

[1]Zhengzhou University of Light Industry, No. 5 Dongfeng Road, Jinshui District, Zhengzhou City, Henan Province, China
[2]Tianjin University of Technology and Education, No. 1310 Dagunan Road, Hexi District, Tianjin, China
[3]Corresponding author

[4]3215711845@qq.com
[5]593459421@qq.com
[6]1533601449@qq.com
[7]27412397@qq.com
[8]109169804@qq.com

Abstract. Against the backdrop of rapid economic growth and continuous expansion of road networks in China, the planning, design, greening, and beautification of roads at all levels have entered a systematic implementation phase. Particularly noteworthy is the emergence of dynamic road landscape design as a major focus in the research on urban road beautification in the new era. This paper proposes a road dynamic landscape optimization design scheme based on the fuzzy clustering algorithm. It analyzes the primary elements constituting dynamic road landscapes and summarizes the fundamental principles for designing such landscapes. The fuzzy clustering method is employed to classify different road landscapes, optimizing the design system. Through simulation experiments, the effectiveness of the proposed scheme is validated, with results indicating an 8.34% higher accuracy compared to traditional methods. The study suggests that such road design not only meets basic traffic needs but also achieves greening and beautification effects while catering to users' visual and psychological needs, showcasing the unique cultural, historical, and lifestyle characteristics of the city. Furthermore, this design fosters harmonious integration between roads and their ancillary structures and surrounding buildings, significantly improving the city's landscape and living environment.

Keywords: Fuzzy Clustering, Road, Dynamic Landscape

1. Introduction

The concept of "motion," particularly significant in Marxist philosophy, distinguishes objects into static and dynamic states. Here, "motion" is defined as the change in the position of an object in space [1], while "dynamics" describes the process of change and development in things, namely the change in position coordinates over time [2]. In dynamic landscape design, the systematic integration of various design elements forms interactive relationships between people, space, and landscapes [3]. This stands in stark contrast to static park landscapes, where the relative position change between individuals and landscapes is minimal [4]. When driving on roads, observers experience continuous changes in their relative position to the surrounding landscape, resulting in a constantly evolving scenery. While the landscapes around urban roads remain fixed, the dynamic beauty emerges due to people's movement. In designing road landscapes, considering aesthetics in dynamic time is deemed more important than in static time [5]. Roads are not merely conduits connecting different locations; they also serve as spaces for residence and cultural exchange, forming the material foundation of socio-cultural continuity [6]. Designing roads requires addressing both transportation functionality and users' physiological and psychological needs to create a comfortable environment. Road design is not just a practical matter; it involves a comprehensive understanding of aesthetics, culture, and psychology. By considering these diverse needs, a city space that is both practical and beautiful can be created.

As an artificial structure closely connected to the ground, roads exhibit a distinctive linear form in a non-natural environment [7]. Road landscapes encompass the internal scenery visible to road users and the natural ecological landscapes surrounding the roads [8]. These landscapes manifest the linear structure of the road and its surrounding environment while driving. Internal landscape elements such as vegetation, sidewalks, structures, and various configurations, along with natural ecological landscapes like forest belts, cultural elements, and buildings on both sides, constitute road landscapes. Road landscapes blend natural and social characteristics, integrating the functionality, utility, and artistry of landscapes, forming a comprehensive landscape system [9]. In classifying and analyzing these landscapes, this paper adopts the cluster analysis method. This method, based on the principle of categorizing similar objects into groups, uses multivariate statistical analysis to classify samples, aiming to categorize samples into meaningful or useful categories. Specifically, this study employs the fuzzy clustering algorithm, which simulates adaptive functionality, effectively reducing the execution cost of the algorithm [10]. Through this approach, road landscape design can be more effectively understood and optimized, ensuring both beauty and practicality.

Roads play a crucial role in cities, acting as both the nervous system and circulatory system, with their landscapes serving as dynamic linear elements that form a key part of the urban landscape. They not only shape the city's appearance but also influence the style of road spaces, people's living conditions, and communication environments, serving as vital symbols of the urban image. Optimizing road landscapes contributes to improving the traffic environment, offering people a pleasurable visual experience, and achieving a harmonious blend of functionality and aesthetics in roads. This study focuses on collecting and processing vertical road load spectrum data, determining key parameter types and quantities that reflect road conditions through extraction and filtering. Subsequently, a fuzzy clustering algorithm is employed to classify road surfaces and identify unknown road conditions. The innovation of this work lies in:

(1) Simulating adaptive functions using the fuzzy clustering algorithm, effectively reducing the execution cost of the algorithm.

(2) Establishing key features for the optimization of road dynamic landscape design and implementing the optimization and identification of road dynamic landscape design systematically.

The research framework of this paper is as follows:

The first part is the introduction, providing an overview of the research background and value, stating the research objectives, methods, innovations, summarizing the relevant literature, and proposing the research approach. The second part is the research methodology, primarily utilizing the fuzzy clustering method to optimize the combined subject design approach. The third part is the experimental section, conducting experimental validations on the dataset and analyzing the model's performance. The fourth part is the conclusion and prospects, summarizing the main content and results of the research, drawing conclusions, and indicating directions for future research.

2. Research Methodology

2.1. System Construction for Road Dynamic Landscape

The research on road dynamic landscapes aims to create a pleasant experience for road users. As key projects at the national or local level, the planning and construction of these roads have received approval from relevant government departments. During the project approval phase, the nature, function, and short-term and long-term construction goals of the roads have been determined. Based on these goals, road design considers a series of factors, including natural factors such as the geographical range, terrain, site conditions, and regional characteristics of the road, as well as cultural heritage, historical sites, and local customs. Building upon these considerations, road design should adhere to several key principles:

(1) Topographical Adaptability Principle: Design should utilize existing topography, striving to achieve harmonious coexistence with the natural environment, and simultaneously achieve excellent visual and environmental effects with minimal workload.

(2) Environmental Protection Principle: Road construction should prioritize environmental protection, adhering to the principles of sustainable development to ensure harmony with the ecological environment and minimize negative impacts on the environment.

(3) Aesthetic Functionality Principle: Design should integrate aesthetic theories, ensuring that road landscapes not only meet aesthetic standards but also fulfill functional requirements, providing a comfortable experience for drivers and passengers.

(4) Distinctive Style Principle: As a link within the city and connecting internally and externally, road landscapes should reflect the characteristics and personality of the city.

(5) National Standards Principle: Construction should comply with national building standards, regulations, laws, and policies.

(6) Human-Centered Principle: Road design should consider users' perspectives, meeting both physiological and psychological needs.

(7) Integrity Principle: In the multitude of topics within urban design, the integrity of road dynamic landscape design is crucial to prevent isolated planning and design of roads and their surrounding environment. This pursuit of integrity can be considered and achieved from two main dimensions: (a) Citywide Perspective: From the viewpoint of the entire city, the landscape design of urban roads should reflect the unique image and personality of the city. Design should not be limited to individual roads but should be viewed as part of the city's public space, seeking harmony with the overall urban environment. This unity is not only visual but also involves the integration of urban culture, history, and social characteristics. Designers need a deep understanding of the city's identity and features, ensuring that road landscapes not only showcase the city's unique appearance but also align with the overall planning and development direction of the city. (b) Road-Level Perspective: Starting from each road itself, consider the road as an independently designed entity. This means that buildings, greenery, color schemes, historical and cultural elements on both sides of the road should coordinate with the design style and functional requirements of the road itself. Designers should avoid focusing solely on the road surface or individual elements but should comprehensively consider the relationship between the road and its surrounding environment, achieving unity in visual, functional, and cultural aspects.

Road landscapes constitute a diverse landscape system that integrates natural and human elements. Natural landscapes include factors such as climate, hydrology, soil, geology, topography, and biology, while human landscapes involve structures, farmland, artificial plants, and artificial structures. Roads and their surrounding areas form a macroscopic system shaped by terrain changes and various factors, especially human activities, reflecting the interaction and constraints between humans and the environment, embodying the fusion of culture and nature. In this paper, road landscapes are divided into two main parts for study: internal road landscapes and external road landscapes. Internal road landscapes refer to the landscapes formed by the road itself, including the route, road surface, and roadbed. External road landscapes refer to the landscapes along the road within the road's land-use range, primarily composed of road structures, plantings, and other elements. Through such classification, this paper aims to analyze and study road landscapes more comprehensively and systematically, facilitating a better understanding and optimization of road and surrounding environment design. Refer to Figure 1 for an illustration.

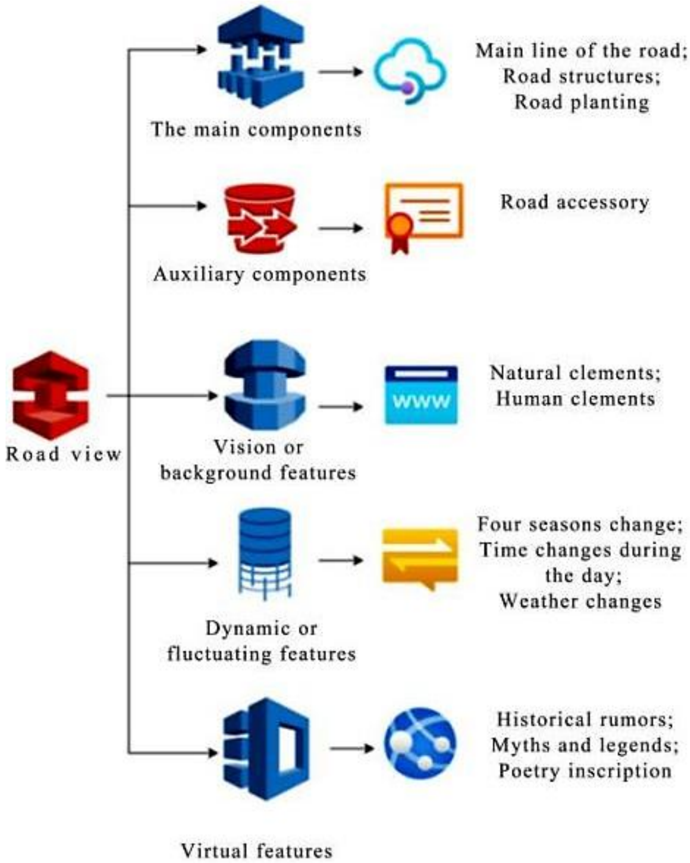

Figure 1. Elements of Road Landscape

2.2. System Construction of Road Dynamic Landscape

The objective of dynamic landscape design is not only to showcase aesthetics but also to adapt and integrate with the local natural environment. In the construction of ecological landscapes, diverse vegetation combinations should be considered to create a mixed plant spatial structure. The varied heights, colors, and forms of trees all contribute to the comprehensive beautification of the landscape, emphasizing the ecological and landscape features of the city.

In terms of technical methods, this paper adopts the Goal Function-based Fuzzy C-Means (FCM) clustering method. This method transforms cluster analysis into a constrained nonlinear programming problem and optimizes it through an iterative process to achieve the best fuzzy partition and clustering results for the dataset. This method is concise in design, applicable to a wide range of problems, and can be viewed as an optimization problem using classic nonlinear programming theory from mathematics. It is easy to implement through computers. Therefore, in the context of the application and development of computer technology, the goal function-based fuzzy clustering algorithm has become a new research hotspot.

Fuzzy systems are knowledge or rule-based systems. They use linguistic descriptions as fuzzy rules and perform reasoning and calculations based on these rules to accomplish specific tasks. The main components of these systems include a fuzzy interface, a fuzzy reasoning mechanism, a knowledge base, and a defuzzification interface. The design and application of these systems make the handling of complex problems more flexible and efficient. The structural components of a fuzzy system are illustrated in Figure 2.

DOI: 10.54254/2753-8818/34/20241143

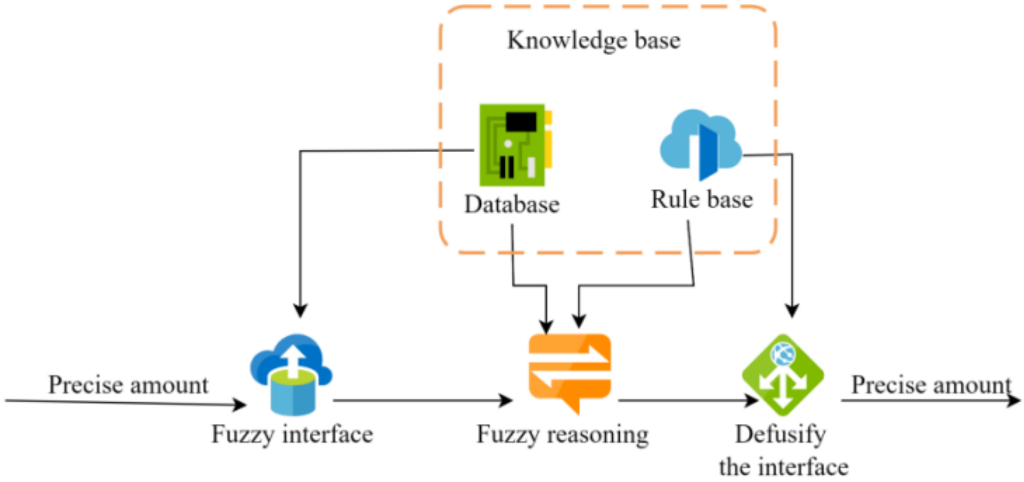

Figure 2. Basic Block Diagram of Fuzzy System

The core feature of the dynamic clustering algorithm lies in its clustering process, which involves continuous iterative steps. In this iterative process, a common approach is to allow data samples to transfer between different clustering groups. The flexibility of this method lies in its ability to adapt to changes in samples and the emergence of new information, continuously optimizing the clustering results throughout the iteration process. The dynamic clustering process is illustrated in Figure 3.

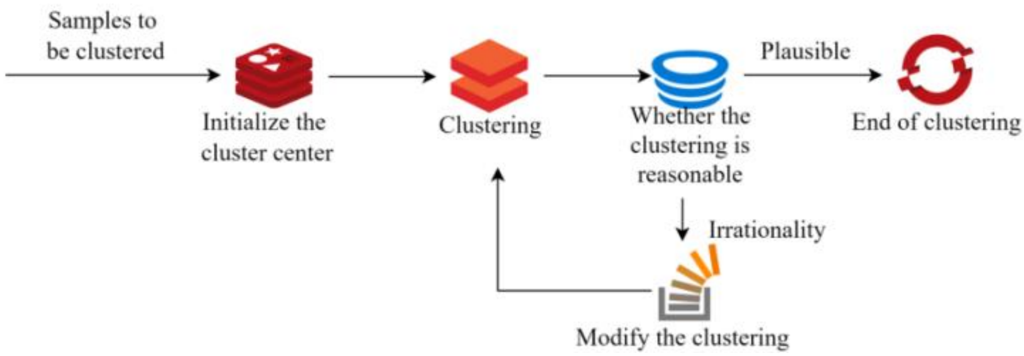

Figure 3. Dynamic Clustering Process

The Fuzzy C-Means (FCM) algorithm represents an enhancement of the traditional C-Means algorithm. In the traditional C-Means algorithm, data partitioning often faces challenges, and the FCM algorithm introduces the concept of fuzzy partitioning to enhance flexibility. In this method, each point in a dataset is assigned a membership degree, with the sum of these membership degrees always maintained at 1. This approach allows the FCM algorithm to handle data partitioning more effectively and flexibly:

$$\sum_{i=1}^{c} u_{ij} = 1, \forall j = 1,2, \dots, n \tag{1}$$

$n\, X_{ii}(i = 1,2, \dots, n)c$In the traditional Fuzzy C-Means (FCM) algorithm, vectors are partitioned into fuzzy groups, and the cluster centers for each group are computed to minimize the value function of dissimilarity indices. The general form of FCM's value function (or objective function) is:

$$J(U,V)=\sum_{i=1}^{c}J_i=\sum_{i=1}^{c}\sum_{j}^{n}u_{ij}^{m}d_{ij}^{2} \tag{2}$$

u_{ij} $d_{ij}=\|v_i-x_j\|i \quad j\ v_i im\in[1,\infty]$, where is between 0 and 1; is the Euclidean distance between the cluster center and the sample data point; is the cluster center of the class; is a weighted exponent. This constitutes a constrained optimization problem with respect to the independent variable. By employing the necessary conditions of extremum points, the derivatives with respect to and are set to zero: $(U,V)J(U,V)\,u_{ij}\,v_i$

$$\frac{\partial J}{\partial u_{ij}}=0,\frac{\partial J}{\partial v_i}=0 \tag{3}$$

Results:

$$v_i=\frac{\sum_{j=1}^{n}u_{ij}^{m}x_j}{\sum_{j=1}^{n}u_{ij}^{m}} \tag{4}$$

$$u_{ij}=\frac{1}{\sum_{k=1}^{c}\left(\frac{d_{ij}}{d_{kj}}\right)^{\frac{2}{m-1}}} \tag{5}$$

The fundamental principle of the Fuzzy C-Means (FCM) algorithm is to partition the sample set into c categories. Initially, the algorithm selects c initial cluster centers, and then, based on the nearest distance principle, assigns each sample to the category represented by the nearest cluster center. Subsequently, through an iterative process, it continuously calculates and updates the cluster center for each category. According to the newly determined cluster centers, the classification of samples is adjusted accordingly, and this process continues until iterative convergence is achieved. After convergence, the FCM algorithm ultimately determines the cluster centers for each category and the degree of membership of each sample to each category, thereby achieving the partitioning of fuzzy clusters. The entire FCM algorithm is an iterative solution process aimed at minimizing a specific objective function.

3. Results Analysis and Discussion

Roadscape design considers the four-dimensional nature of space, with spatial variation as its core element. The layout, structure, texture, color, and greenery selection of roads should adapt to the changes in the external environment in a natural, smooth, and continuous manner. In design art, points, lines, surfaces, and volumes are fundamental modeling elements, and these apply similarly to the spatial form design of roadscape. In this spatial form, lines play a crucial role. Roads are fundamentally linear spaces, and their curved or straight characteristics significantly impact the spatial morphology of the landscape and people's visual perception of the roadscape. The spatial morphology of straight roads exhibits clear directionality and strong continuity, with environmental elements along the route enhancing its spatial characteristics. Visually, straight roads present expansive and magnificent landscapes. In contrast, curved roads appear smooth, vivid, and dynamic. Driving on curved roads, the buildings and landscapes on both sides continuously change with movement, adding rich visual layers to the road's morphology. For zigzag roads, the spatial form undergoes a sudden change at turning points, providing a visual experience of "suddenly enlightened" or "encountering in a narrow space." This intense spatial sensation can leave a profound visual and psychological impression. Through such designs, roadscape becomes an expressive and impactful element in urban space.

When constructing the fuzzy system prediction model, a numerical range of 600 to 1500 was employed as input. These input values represent the actual observed values of the model. Based on these actual values and empirical knowledge, the model determined the parameter selection of the membership function, the selection of fuzzy subsets, and the extraction of rules. Subsequently, the results were analyzed using the established fuzzy system file for prediction. Figure 4 illustrates the output curve obtained through fuzzy prediction. To observe the prediction effect in more detail, the first 200 predicted data points were selected for local analysis. Figure 5 presents a comparison between the values predicted by the fuzzy system and the actual values, displaying the local prediction curve. Through this approach, the fuzzy system prediction model can effectively perform data analysis and prediction.

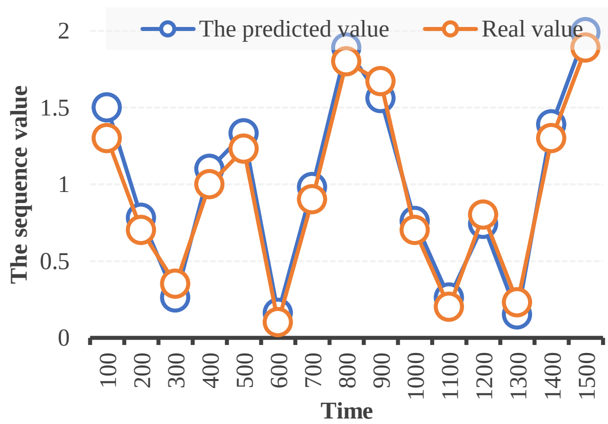

Figure 4. Predicted values and actual values obtained through the fuzzy system.

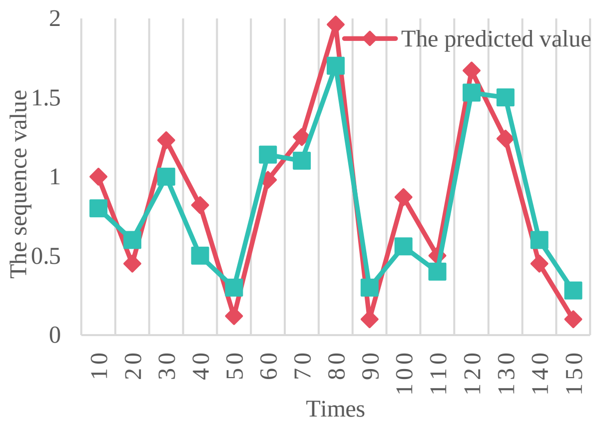

Figure 5. Local predicted values and actual values obtained through the fuzzy system.

From Figure 4 and Figure 5, it can be observed that the predicted values of the model are generally consistent with the actual values, indicating an overall satisfactory prediction performance. After clustering, the initial fuzzy clustering model exhibited a notably shorter training time, and the training time to achieve optimal training results was also less, enabling the rapid attainment of satisfactory training output curves.

4. Conclusion

A road dynamic landscape optimization design scheme based on fuzzy clustering algorithms is proposed in this study. Firstly, the main elements constituting road dynamic landscapes were analyzed, and design principles were summarized. Subsequently, the fuzzy clustering method was employed to classify roadscapes, and the design system was optimized. Through simulation experiments, the results showed

DOI: 10.54254/2753-8818/34/20241143

an 8.34% improvement in accuracy compared to traditional methods, indicating that the combined determination of clustering classification and clustering effectiveness can effectively meet the requirements of practical problems. Additionally, this research explores a theory and algorithm for automatically determining the optimal number of clusters, reducing human empirical intervention, and enhancing the automation and objectivity of fuzzy clustering algorithms. In the realization of natural landscapes on urban roads, the selection and design of plants are crucial. The long-term maintenance of most garden trees is relatively simple. However, for small trees or large shrubs, their advantages should be considered during design to achieve minimal pruning and modeling through the use of natural forms. This not only promotes healthy growth but also reduces long-term maintenance costs, contributing to the construction of a conservation-oriented social environment. Finally, the study also discusses the impact of road dynamic landscapes on the spatial pattern of urban areas, especially the influence of different road network forms on the spatial pattern, providing a broader perspective and ideas for future road landscape design.

References

[1] (2018). A fuzzy clustering method for large image data based on multi-agent systems. Journal of Real-time Image Processing, 23(4), 17.
[2] (2017). Fuzzy clustering response to different threshold determination algorithms in spectral change vector analysis of the western Himalayas, India. Journal of Mountain Science, 24(5), 2, 78.
[3] (2022). Neural network modeling based on fuzzy clustering enhanced by clustering with support vector and regularization techniques. Neural Computing, 35(1), 48.
[4] (2018). Multifunctional Web service clustering based on LDA and fuzzy c-means algorithm. Journal of Central South University, 34(3), 92.
[5] Hao, Z., & Liu, S. (2021). Mountainous loess mechanical properties based on fuzzy clustering and basketball venue construction (Retracted Volume 14, Art. 1720, 2021). Arabian Journal of Earth Sciences, 21(5), 178.
[6] (2022). Deep instance envelope network and inter-layer difference minimization for imbalanced learning algorithm based on multi-layer fuzzy c-means. Applied Soft Computing, 54(3), 133.
[7] (2020). Image segmentation using adaptive entropy-weighted fuzzy clustering algorithm with spatial information. Applied Soft Computing, 86(3), 57.
[8] (2021). Fuzzy c-means clustering algorithm optimization with principal component analysis combined with Minkowski and Minkowski-Chebyshev distance. International Journal of Fuzzy Systems, 35(2), 76.
[9] Chen, Q., Lin. (2017). Continuous ankle joint angle estimation in functional electrical stimulation using neuro-fuzzy systems combined with clustering algorithms. Journal of the Chinese Society of Mechanical Engineers, Series C: Journal of Mechanical Engineering, 38(1), 12.
[10] (2018). Modeling and application of fuzzy adaptive minimum spanning tree in tourism agglomeration division. Systems of Knowledge, 143(2), 317.