

Intelligent sprinkler irrigation system based on K-Means algorithm

Chunlong Fu, LingXiao Zheng, Teng Sheng*, Xuelian Zhang
Department of Computer, Sichuan University Jinjiang College, Meishan, Sichuan, China

ABSTRACT

At present, the layout of sprinkler position in the irrigation system mainly depends on manual design. When the irrigation scale is large, the manual layout is difficult to realize, and the unreasonable layout is easy to cause problems such as sprinkler irrigation equipment and water resources waste. In this paper, the k -means algorithm in machine learning is applied to agricultural irrigation, and the concept of intelligent sprinkler irrigation layout design is proposed. Firstly, the sprinkler irrigation area is simulated and stored in the computer based on the inner and outer point discrimination algorithm of polygon, and then the irrigation area is clustered and divided based on the k -means algorithm to obtain each cluster. The central point of each cluster is the best location for sprinkler installation. In the comparative experiment of irrigation areas with different shapes, it is concluded that the irrigation coverage and irrigation uniformity coefficient have a good performance. Compared with manual design, the intelligent irrigation layout proposed in this paper is more intelligent and reasonable.

Keywords: Sprinkling irrigation, computer simulation, k -means algorithm, coverage

1. INTRODUCTION

Water saving irrigation obtains the maximum yield or income with the minimum water consumption. It is also an irrigation measure to maximize the crop yield and output value per unit of irrigation water. Sprinkler irrigation, drip irrigation and micro sprinkler irrigation have become the mainstream development direction in the field of international water-saving irrigation because of their strong water-saving ability, controllable irrigation process and good irrigation effect^{1,2}. Based on the purpose of rational utilization of water resources and reducing waste, we select more appropriate sprinkler irrigation types from the agricultural sprinkler irrigation system^{3,4} according to the applicable areas for research. Sprinkler irrigation system can be divided into unit sprinkler irrigation system and pipeline sprinkler irrigation system⁵. Unit sprinkler irrigation system is mainly used in areas with less irrigation times. Due to its mobility, it has less demand for equipment investment; Pipeline sprinkler irrigation system is more suitable for areas with scarce water sources and few water intake points. It not only has convenient operation and high efficiency, but also has advantages in automatic control. In engineering, there are two main fixed pipeline nozzle layout methods^{6,7}: square and triangular combined layout. If the terrain is complex and the number of nozzles is designed to be large, it is difficult to design the best nozzle position according to the current manual experience, resulting in uneven crop irrigation and waste of water resources. This paper presents an intelligent sprinkler irrigation system based on K-means algorithm⁸ on how to automatically select the best nozzle layout.

2. MATERIALS AND METHODS

2.1 Land simulation and construction

In order to facilitate the digital analysis of sprinkler irrigation system, the experimental land is simulated in this paper. By surveying and mapping the experimental land, the two-dimensional plan of the top view angle of the land is obtained. The edge of the polygon in the two-dimensional plan will be used as the boundary of the simulated land. Then evenly distributed points are generated in the interior of the polygon to simulate the plants in the land. In this way, the simulated soil map is obtained by computer simulation.

2.1.1 Land Boundary Range Construction. The land boundary range is constructed. In the two-dimensional plan of the experimental land, the vertices of the polygon are arranged clockwise, and the points obtained after arrangement are used

* 1206328503@qq.com

as the land boundary data set. In this way, the boundary information of land is obtained. Through the mapping relationship, the contour information of land can be simulated.

2.1.2 Land Data Set Construction. Assuming that the plants are evenly distributed, the points of the grid data generated by the simulation are used as plants. Because it is difficult to directly generate uniform and dense grid points in the simulated land, we first build a large rectangular area, distribute grid points in the rectangular area, then put the simulated land into the rectangular area, and classify the points by using the polygon inner and outer point discrimination algorithm^{9,10}. If the plants fall in the simulated land, then the plant is kept, otherwise it will be deleted, so that there are uniform plants only in the simulated land, and finally the data set of the simulated land is obtained.

2.1 K-means Algorithm

K-means algorithm is a very classic algorithm in machine learning⁸. The algorithm divides a data set into several groups or classes through continuous iterative clustering, and finally obtains the optimal division. The traditional *K*-means algorithm has a local optimal solution. It has certain requirements for the initial center point and needs to distribute the initial point as evenly as possible. However, in this experiment, because the data set to be divided is uniformly distributed scattered points, the traditional K-means algorithm can still get the global optimal solution when the initial points are randomly selected.

The specific process of K-means algorithm is as follows:

- (1) First, *K* sample points are randomly selected from the simulated land data set $X = X_1, X_2, \dots, X_n$ as the initial center points of clustering, and then the *K* empty sets $C = C_1, C_2, \dots, C_k (i=1, 2, \dots, K)$ generated by initialization are used to store the simulated land data set *X*.
- (2) According to the proximity principle, all points X_i in the data set *X* are allocated to the corresponding cluster C_i , and finally a new cluster *C* is obtained.
- (3) According to the new clusters obtained above, the center point of each cluster is taken as the new *k* center points.
- (4) Steps 2 and 3 above are repeated, when the clustering center is no longer changed, the algorithm ends.

2.3 Nozzle position layout

Through the application of *K*-means clustering algorithm to the simulated land data set, the land is divided into the optimal *K* areas after many times of land division, and finally the sprinkler is installed at the center of each area. The algorithm is described as follows:

Input: Vertex information of polygon $P = P_1, P_2, \dots, P_n$.

Step 1: The polygon vertex *P* is put in and the rectangle with the minimum size of the polygon is calculated.

Step 2: All grid points are traversed within the rectangle to judge whether these points are points within the polygon, and the points within the polygon are taken as the simulated land data set.

Step 3: Different *K* is taken, *k*-means algorithm is used to cluster and the simulated land data set is divided.

Output: Division results are obtained corresponding to the number *k* of different center points.

3. EXPERIMENT

3.1 Construction and division of land simulation map

Firstly, the regular square is selected as the simulated land in this experiment, and the simulation map of the land is constructed according to the method in Section 2.1. The evenly distributed points in the map are the simulated plants. The simulation map of the land is shown in Figure 1a below.

The land simulation zoning map is completed by *K*-means algorithm. When $k = 4, 8$ and 12 , the division results of the simulation map are shown in Figures 1b-1d respectively. Black dot “.” refers to the central point of each area, which is the location where the nozzle is installed.

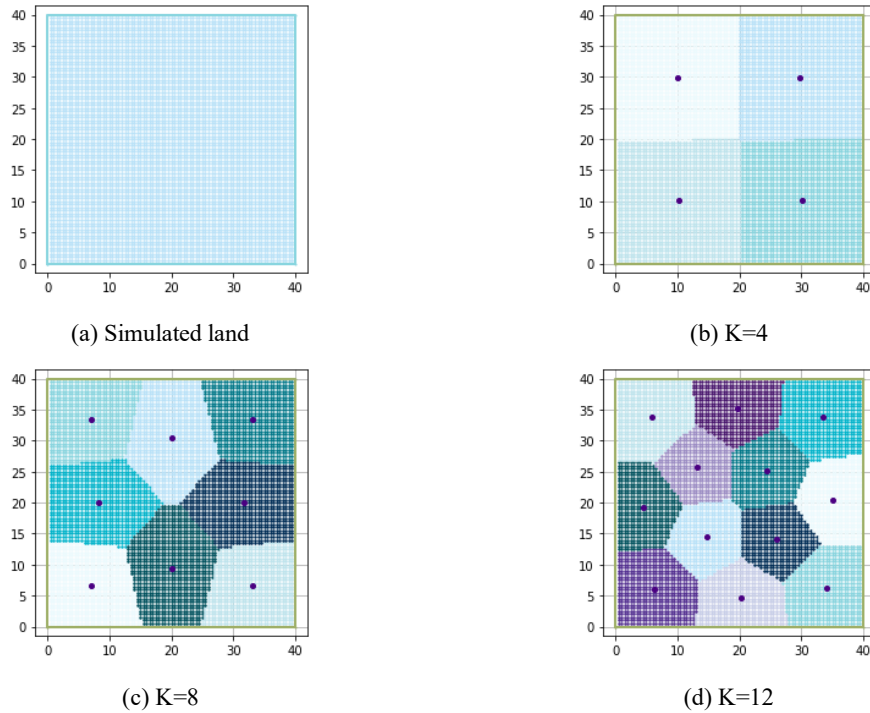


Figure 1. Simulated land division.

3.2 Sprinkler irrigation coverage

In order to study the reliability of the algorithm in this paper, the sprinkler irrigation area coverage (CVR) is introduced as the evaluation index. The coverage rate is the ratio of the spraying area CS of garden sprinkler irrigation to the total area S of garden ($CVR = CS/S$). In this paper, a buried rotary jet nozzle with a range of about 0 to 15 meters is used to discuss the change of coverage when the parameters of range radius R and number k of nozzles are taken as different values.

3.2.1 The Solution Method of Sprinkler Irrigation Coverage. Input: Sprinkler radius R , number of nozzles K , land simulation data set X .

Step 1: The division results of K clusters are obtained by dividing the simulated land data set X by K -means algorithm.

Step 2: M is obtained by counting the number of points X_i in the sprinkler irrigation area of the land simulation data set X

Step 3: Coverage $CVR = M / N$, where the denominator is the number of sample points in the simulated land.

Output: Coverage CVR

3.2.2 Sprinkler Irrigation Coverage Experiment. In order to study sprinkler irrigation coverage, the simulated land s is obtained by simulation technology. At the same time, different clustering results can be obtained when taking different K values based on K -means algorithm. In this paper, $k = 12$ is selected as an example to obtain the divided simulation diagram, as shown in Figure 2a.

In order to show the experimental content more vividly, this paper selects the rotating jet nozzle for the experiment when $k = 12$ and $R = 9$. The results of simulated land division are shown in Figure 2a. In Figure 2b, the blue and yellow areas are covered by the spraying range of one and two nozzles respectively, and the red area (less) indicates that it is covered by the spraying range of three or more nozzles.

In order to show the relationship between CVR and R and K more generally, when taking different nozzle range radius R and the number of nozzles K , this paper calculates the coverage CRV and draws the R, K -CVR function diagram, as

shown in Figure 2c. From the diagram, it can be found that the range and the number of nozzles are positively correlated with the coverage. When the range R is constant, the more the number k of nozzles, the higher the coverage CVR; When the number of nozzles K remains unchanged, the larger the range R is, the higher the coverage CVR is, and when the range R reaches a certain degree, the rising rate of CVR will be lower when the range R is increased.

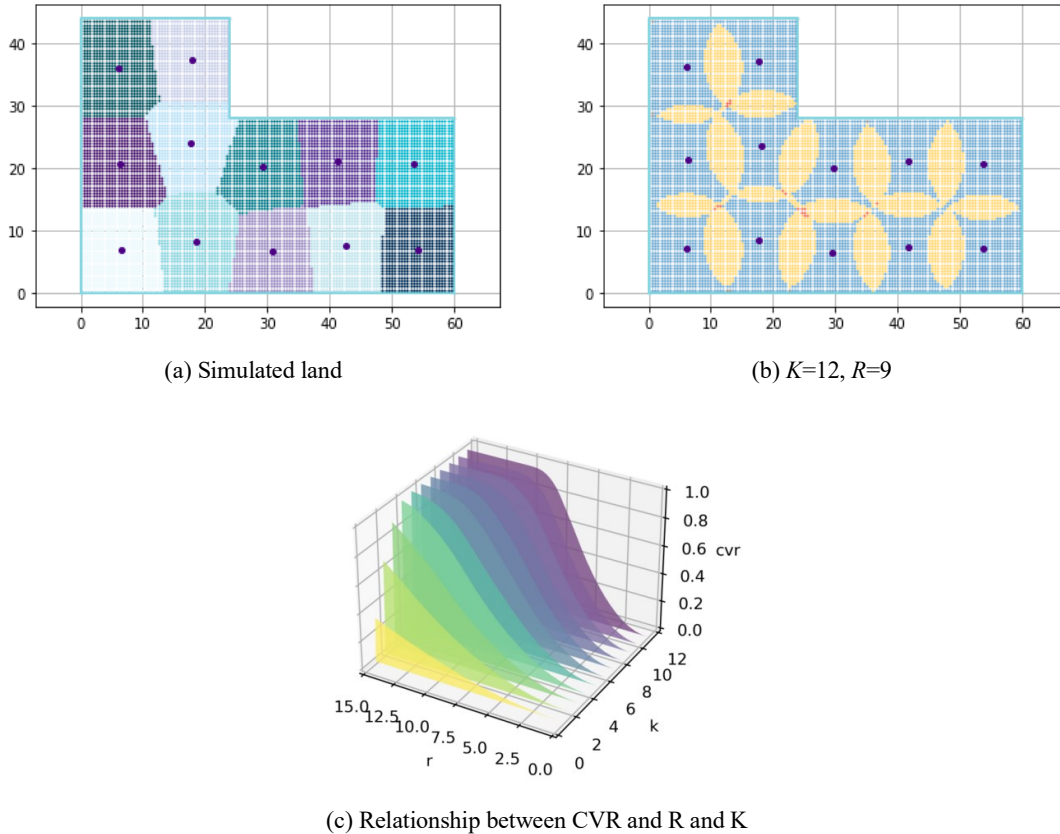


Figure 2. Sprinkler irrigation coverage.

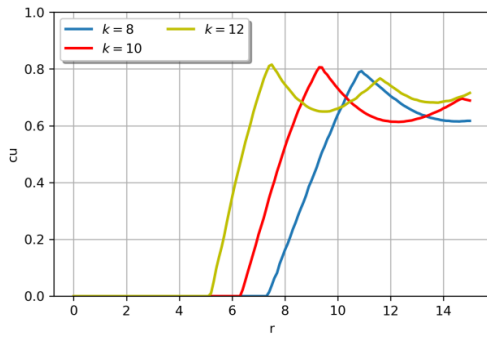
By selecting the range R and the number k of nozzles, we can select the parameters that meet the conditions of nozzle parameters, uniform spraying coverage and convenient pipe network layout. The R-K-CVR graph can quickly provide an effective reference for the layout of the nozzle.

3.3 Uniformity of sprinkler irrigation

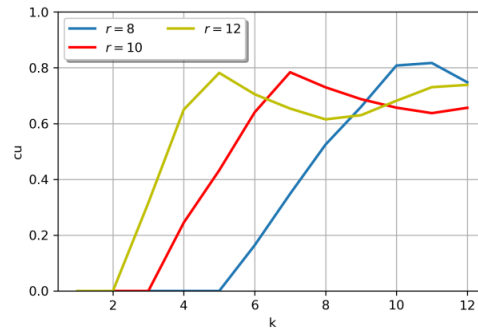
The uniformity of sprinkler irrigation has a great impact on plant growth. The more uniform sprinkler irrigation is, the better plant growth will be. At the same time, it can also save water resources. In this paper, the classical Christensen uniformity¹¹ is used to calculate the sprinkler uniformity of nozzle combination. The calculation formula is:

$$C_u = \left(1 - \frac{\sum_{i=1}^n |h_i - \bar{h}|}{\sum_{i=1}^n h_i} \right) \times 100\%$$

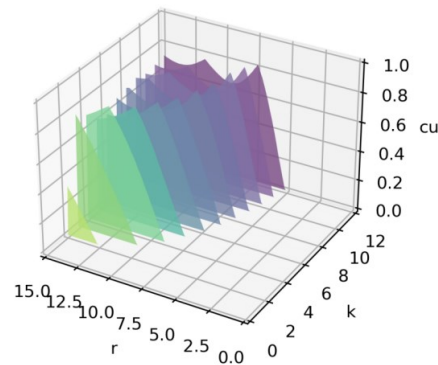
where, C_u represents the uniformity of sprinkler irrigation; n represents the number of plants in the simulated land; h_i indicates the precipitation depth of the i th plant. If the plant is not covered by the water sprayed by any sprinkler, the precipitation depth is 0; If it is covered by only one nozzle, the precipitation depth is 1; If it is sprayed and irrigated by N nozzles, the precipitation depth is n ; \bar{h}_i indicates the average precipitation depth of each detection point.



(a) Relationship between Cu and R



(b) Relationship between Cu and K



(c) Relationship between CU and R and K

Figure 3. Uniformity of sprinkler irrigation.

It can be found from Figure 3a that the sprinkler uniformity first increases, then decreases, and finally increases with the increase of sprinkler radius R. It can also be found in Figure 3b that the uniformity of sprinkler irrigation has the same change law as the number of sprinkler heads. In Figure 3c, the relationship between sprinkler uniformity and sprinkler radius and the number of sprinklers is analyzed. It can be found that the larger the sprinkler radius R, the greater the sprinkler uniformity C_u , and the more the number of nozzles K, the greater the uniformity C_u , but there is also a local maximum in the figure. In order to meet uniform sprinkler irrigation and save resources, the sprinkler radius and the number of nozzles corresponding to the local maximum in the figure can be selected when designing the sprinkler irrigation layout.

4. CONCLUSION

This paper puts forward the layout design of automatic sprinkler irrigation, which combines computer technology with agricultural irrigation design. It can simplify the design of fixed and semi fixed sprinkler irrigation layout, so as to reduce the design difficulty. The practical application of this design method can be as follows:

- (1) In the actual project, as an auxiliary design, the rapid numerical and visual comparison of different layout is carried out, and the design in line with different terrain, different nozzle parameters and different pipe network layout is obtained. And the design can be adjusted manually according to the specific construction conditions, which is in line with the actual situation.
- (2) In the application of new sprinkler irrigation technology, for example, the shape of the spraying range of a single nozzle is a programmable polygon with user-defined shape. Using the characteristics of this design algorithm (and each partition is a polygon), we can achieve full coverage and 0 repetition rate of each partition.
- (3) It can provide a large number of different designs for the measurement and research of spraying uniformity under different nozzles, and reduce the time cost of manual design.

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