Research on Spatial Trajectory Retrieval Method of Athletes Stepping Motion Data

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Abstract. Routine athletes action spatial trajectory data retrieval method can perform the trajectory retrieval to athletes action, but there is the deficiency of low retrieval ability when only the detailed spatial trajectory retrieval of athletes stepping motion is performed, for this reason, the research on spatial trajectory retrieval method of athletes stepping motion data is proposed. Based on the extraction of characteristic information of athlete's stepping motion, the stepping motion R-Tree and its variant space index are determined, and the construction of the spatial trajectory retrieval model of athlete's stepping motion data is achieved. Based on the spatial trajectory index design of athlete's stepping motion data, the spatial trajectory retrieval result is output, and the research on spatial trajectory retrieval method is completed. The experimental data show that the retrieval capability of proposed trajectory retrieval method for athlete's stepping motion is 53.41% better than that of conventional trajectory retrieval, which is suitable for detailed spatial trajectory retrieval of athlete's stepping motion.

Keywords: Athletes · Stepping motion · Spatial trajectory · Retrieval methods

1 Introduction

Conventional athletes' motion data spatial trajectory retrieval methods can perform trajectory retrieval on athletes' movements, but when performing detailed spatial trajectory retrieval on athletes' stepping movements, due to the limitations of spatial trajectory retrieval models, there is a shortage of low retrieval ability [1]. Thus, the research on spatial trajectory retrieval method of athlete stepping motion data is proposed. The inclination angle, minimum enclosing rectangle MER and tightness, movement speed, circumscribed rectangle length and width, and rate of change are extracted and analyzed as the characteristics of the stepping motion, and the stepping motion R-Tree and its variable spatial index are determined to achieve the construction of spatial trajectory retrieval model of the athlete's stepping motion data; 2^f reverse tables are determined. Each record corresponds to a stepping motion data file. The record contains the segmentation of the file and the corresponding speciality vector to complete the spatial trajectory index design of athletes stepping motion. The spatial trajectory retrieval results are output, and the proposed spatial trajectory retrieval method of athlete's stepping motion data is completed. To ensure the validity of the

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designed spatial trajectory retrieval method and simulate the athlete's experimental environment, two different spatial trajectory retrieval methods for data are used to perform the retrieval capability simulation test. The experimental results show that the spatial trajectory retrieval method for data is highly effective.

2 System Objective and Analysis

The research on spatial trajectory retrieval method of athletes stepping motion data mainly includes:

(1) The main axis area of the target area is established, and the linear whose rotational inertia reaches the minimum value is used to determine the rotational inertia of the target area D and optimize the extraction of the stepping motion characteristic information of the athlete.
(2) Building R^+-Tree solves the intersection of R-Tree related nodes, resulting in poor search performance. The number of invalid queries is reduced and redundant information is controlled.
(3) The exact hit $\subset$k measures the similarity so that F[Q] happens to be the subspace trajectory sequence from the k position in F[D], and the spatial trajectory retrieval result of the stepping motion data is output.

3 Construction of Spatial Trajectory Retrieval Model of Athletes Stepping Motion Data

The hierarchical motion model is used to describe the stepping motion of the athlete. The model uses the kinematic chain of stepping motion to simulate the connection state of each joint. Each joint is organized into a tree structure. There is a parent node for each node except the root node. It can also rotate in the parent node's coordinate system. The root node can not only rotate but also translate. The athlete's stepping motion model can be described as:

$$V(t) = [T_{root}(t), R_{root}(t), R_1(t), R_2(t), \ldots R_n(t)] \tag{1}$$

where $T_{root}(t)$ and $R_{root}(t)$ are used to describe the translation and rotation of root node; $R_n(t)$ is used to describe the rotation of the joint around the parent node. The three-dimensional coordinate curve is the spatial trajectory of the athlete's stepping motion data.

3.1 Extraction of Athlete's Stepping Motion Characteristics

Before indexing the spatial trajectory of the athlete's stepping motion data, firstly the characteristics of the stepping motion needs to be extracted, and the index is completed according to the extracted characteristics. There are great differences in the speed and direction of the athlete's stepping motion. Therefore, the slope angle, the minimum enclosing rectangle MER and the tightness, the movement speed, the length and width of the circumscribed rectangle, and the rate of change are taken as the characteristics of the stepping motion to be analyzed.

Because the object of analysis is the human body, the athlete's inclination to fall within a certain range can be considered as a fall. According to the principle, the principal axis of the target area can be described as a straight line that the rotational inertia of the target area D reaches the minimum value. The rotational inertia of the target area D is [2]:

$$I = \iint [(x - \bar{x}) \sin \alpha - (y - \bar{y}) \cos \alpha]^2 f(x, y) dxdy \tag{2}$$

where α is used to describe the angle between the athlete center coordinates $(\bar{x}, \bar{y})$ and axis; f(x, y) is used to describe the binary distribution of images of the athlete's stepping motion, x is used to describe the abscissa of athlete's position and y is used to describe the ordinate of athlete's position.

For convenience of calculation, it can be simplified as [3]:

$$I = \mu_{20} \sin^2 \alpha + \mu_{02} \cos^2 \alpha - 2\mu_{11} \sin \cos \alpha \tag{3}$$

where is used to describe the center distance. To minimize I, let dI/da = 0, namely, $\mu_{20} \sin 2\alpha - \mu_{02} \sin 2\alpha - 2\mu_{11} 2 \cos \alpha = 0$, then the angle of inclination can be obtained through $\alpha = (1/2) \tan^{-1}[2\mu_{11}/(\mu_{20} - \mu_{02})]$, the extraction process of minimum enclosing rectangle MER and the tightness is as follows:

The minimum enclosing rectangle MER requires that the principle axis of the athlete's stepping motion needs to be determined, and then trimmed from the vertical direction of the spindle and the spindle to obtain the minimum enclosing rectangle MER, MER value can be obtained by the formula [4]:

$$MER = A_{area}/A_{MER} \tag{4}$$

where A_{are} is used to describe the area of the athletes' stepping motion. A_{MER} is used to describe the area of MER.

Assuming that the centroid of the k-th frame of athlete's stepping motion image is described by (x_k, y_k), the displacement between two adjacent images can be described as: $s_k = \sqrt{(x_{k+1} + x_k)^2 + (y_{k+1} + y_k)^2}$. The selected video frame rate is 30 frames/s, that is, the time interval between two adjacent frames is 1/30 s. The rate at which the current athlete performs stepping motion can be obtained by the formula: $v_k = s_k/t = 30s_k$. Through the above process, the rate of the stepping motion image of each frame of the athlete is determined, and the average rate of the stepping jump of the athlete is obtained. This section uses the average rate instead of the athlete's stepping rate, which is regarded as one of the characteristics of the stepping motion of the athlete [5]. The average rate can be obtained by the formula:

$$\bar{v} = \frac{1}{n}\sum_{k=1}^{k \leq n-1} v_k \tag{5}$$

where n is used to describe the number of sample frames. The extraction process of circumscribing rectangle length-width ratio and rate of change is to determine the circumscribed rectangular length-width ratio P, a, it can be obtained by the formula: $P_{rop} = L_{MER}/W_{ME}$, where L_{MER} is used to describe the length of MER; W_{MWR} is used to describe the width of MER. The rate of change is compared every two frames. Assuming that the length-width ratio of the two frames are P_{fomor} and $P_{current}$, the rate of change of current length-width ratio can be described as follows:

$$\mathrm{P} = |\mathrm{P}_{\mathrm{current}} - \mathrm{P}_{\mathrm{fomor}}|/\mathrm{P}_{\mathrm{fomor}} \tag{6}$$

In summary, the stepping motion characteristic function of the athlete can be described as:

$$F = [\alpha, MER, \bar{v}, P_{rop}, P] \tag{7}$$

3.2 Determining Stepping Motion R-Tree and Its Variant Spatial Index

R-Tree was first proposed by Guttman in 1984 and is suitable for indexing data area collections. Later, for different applications, the researchers improved R-Tree and formed many variants of R-Tree, such as R^{+}-Tree, R*-Tree, 3DR-Tree, STR-Tree.

R-Tree is a form of B-Tree's development to multidimensional space. It is a deeply balanced tree. It uses the concept of space segmentation and adopts a method of minimum bounding rectangle (MBR), starting from the leaf node and using the minimum rectangular box to frame the space and divide the space. The divided subspace forms the node of the tree. Each node corresponds to a disk page in memory [6]. The non-leaf node disk page uses an array to store the area ranges of all its child nodes. The area that child nodes represent is in the area of the parent node. The disk page of the leaf node uses an array to store all the space objects in its range. R-Tree is a dynamic index structure whose queries can be performed at the same time as insertions or deletions, and does not require periodic reorganization of the tree structure.

Figure 1 shows the basic structure of R-Tree, the outermost smallest rectangle indicates the root node R, it has four child nodes which are a, b, c, d respectively. a, b, c, d in the figure are also leaf nodes, and each leaf node contains several data objects. The entity contained in each non-leaf node in the R-Tree is composed of tuple (cp, rect), cp is a pointer to the child node of the node, and rect refers to the smallest outsourcing box of all child nodes contained in the node. The object contained in each leaf node is composed of tuple (id, loc), id is the identifier of the object in the dataset [7], and to is the spatial coordinate of the object. The number of children (child nodes or objects) contained in each node (excluding the root node) is from m to M, and satisfies m < M/2. The establishment of a good R-Tree needs to satisfy two conditions. One is that adjacent nodes should be clustered on one parent node of the tree as much as possible; the other is that the related nodes of the same layer of the tree has small cross section.

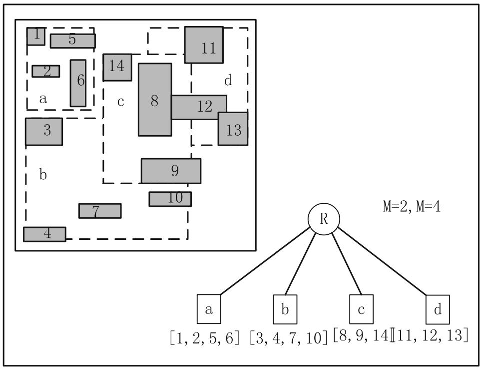

Fig. 1. R-Tree structure

R^+-Tree is proposed for the feature that the intersection of R-Tree related nodes leads to poor search performance. R+-Tree does not allow intersecting areas between related nodes, reducing the number of invalid queries, thereby improving the efficiency of the query [8]. However, for insert and delete operations, to ensure that the spatial areas do not intersect, the efficiency will be reduced, and for data storage with cross-region, the data is redundant, and the more data, the more redundant information.

R*-Tree allows cross-correlation between related rectangles, but constructing R*-Tree takes into account not only the area of the index space, but also the intersection of the index space. The insertion and deletion of nodes by R*-Tree adopts the "forced reinsertion" method to optimize the structure of the tree [9]. 3DR-Tree takes time as another dimension of space, plus the time dimension and space dimension, it can be considered as three-dimensional, so it is called three-dimensional R-Tree. It is a simple indexing method for moving objects, supports space and time search, and is easy to implement. Its advantages are small storage space and high efficiency of time interval query; the disadvantage is that the query performance of the time slice is low, and the index performance gradually decreases as time increases [10].

Using R*-Tree and 3DR-Tree to build TPR-Tree. TPR-Tree supports indexing of any-dimensional space object. It adopts a quad-tree spatial index structure. It can solve future queries of dynamic objects and can be used to solve range queries, nearest neighbor queries, and reverse nearest neighbor queries. The quadtree's spatial index structure is shown in Fig. 2.

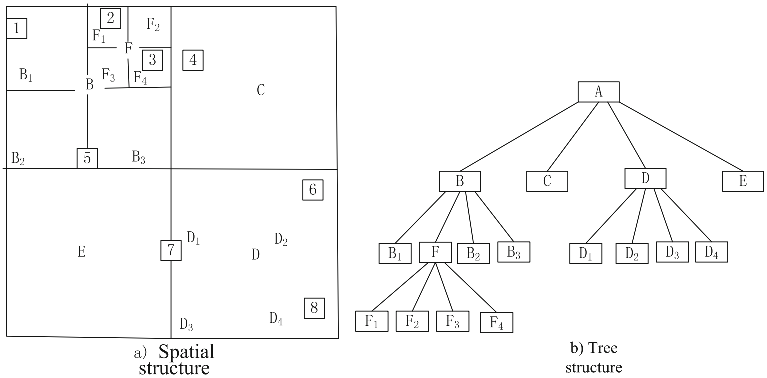

Fig. 2. Quadtree's spatial index structure

Based on the extraction of characteristics of the athlete's stepping motion, using the R-Tree athlete's stepping motion and its variant spatial index, the spatial trajectory retrieval model of the athlete's stepping motion data is constructed.

4 Realization of Spatial Trajectory Retrieval of the Athlete's Stepping Motion Data

4.1 Design of Spatial Trajectory Index of the Athlete's Stepping Motion Data

The index of the spatial trajectory of the athlete's stepping motion data is to construct a spatial trajectory database according to the characteristics of the athlete's stepping motion and use this database for retrieval. Assuming that the database D = (D_1, D_2, …, D_N) is the set of athlete's motion data stream D_n, n ∈ N, it can be seen from the above section that the stepping motion characteristic function F contains five features, namely F:$\varphi \rightarrow (0,1)^5$, where ϕ is the athlete's pose set. Q is used to describe the spatial trajectory sequence of stepping motion, $F[Q] = \bar{v} = (v_1, v_2, \ldots, v_N)$ and $F[D] = \bar{w} = (w_1, w_2, \ldots, w_M)$ are used to describe the F feature sequence of Q and D separately.

In order to create index of database D through the characteristic function F, a standard reverse table technique is used. For each characteristic vector v ∈ $(0,1)^f$, the storage reverse table may be described as L(v), which contains the index of the sequence $\bar{w} = (w_1, w_2, \ldots, w_M)$ whose value m ∈ [1:M}, where v = w_M. In brief, L(v) indicates that D divides the feature vector v.

From the above analysis, it can be seen that the reverse table is an ordered and non-repetitive sequence. When preprocessing, 2^f reverse tables L(v), v ∈ $(0,1)^f$, are established. Since only the F-segmented position is stored in the reverse table, and one F-segmented position occurs only once in one reverse table, the index size is proportional to the number of segments M of D. Not only that, this section also saves the length of each F-segmented to restore the F-segmented frame position. In fact, the database of athletes' motion consists of a plurality of motion files. In order to quickly match the stepping motion data files and the reverse table, a forward table is constructed in this section. Each record corresponds to a stepping motion data file. The corresponding characteristics vector and the segmentation of the file are contained in the record.

4.2 Results Output of Spatial Trajectory Retrieval of the Athlete's Stepping Motion Data

If the F-feature sequences of the spatial trajectories of two players' motion data are the same, the two are considered to be matched. Based on this principle, the spatial trajectory retrieval of the athlete's stepping motion data can be realized. This section measures the similarity by the exact hit ⊂k, which means that F[Q] happens to be the subspace trajectory sequence starting from the k position in F[D], that is:

$$F[Q] \subset_k F[D] :\Leftrightarrow w_k = v_1, w_{k+1} = v_2, w_{k+N-1} = v_N \tag{8}$$

then the results of spatial trajectory retrieval of the athlete's stepping motion data is:

$$H_D(F[D]) = \{k \in [1:M] | L(v) \subset_k F[D]\} \tag{9}$$

thus, the spatial trajectory retrieval of the athlete's stepping motion data is achieved.

5 Experimental Test and Analysis

To ensure the validity of the spatial trajectory retrieval method of athlete's stepping motion data proposed in this paper, simulation experiments are performed. During the test, different athletes were used as test objects to carry out a search capability simulation test. The gender, height, and weight of different athletes are simulated. To ensure the validity of experiment, the conventional spatial trajectory retrieval method of athlete's motion data was used as the comparison object, and the results of the two simulation experiments were compared, and the test data was presented in the same data chart.

5.1 Preparation of Experimental Test

In order to ensure the accuracy of the simulation test process, the test parameters of the test are set. The test process is simulated in this paper, different athletes are selected as the test object, and two different data spatial trajectory retrieval methods are used to perform the search ability simulation test, and the simulation test results are analyzed. Because the analysis results obtained in different methods and the analysis methods are different, the test environment parameters must be consistent during the test. The test data set results in this paper are shown in Table 1.

Table 1. Test data set

Parameters of simulated experiment	Execution range/parameters	Observation
Athlete	Male female ratio = 1:1, male female number = 1:1 Height 170–190, weight 55 kg–95 kg	One-by-one analysis by spatial trajectory retrieval methods of two data
Difficulty of stepping motion	DL0.1–1.0	DL difficulty unit
Simulation system	DJX-2016-3.5	Windows platform

5.2 Analysis of Experimental Test Results

During the experiment, two different spatial trajectory retrieval methods for data were used to work in simulated environment, and the changes in their search capabilities were analyzed. At the same time, due to the use of two different data spatial trajectory retrieval methods, the analysis results cannot be compared directly. For this purpose, third-party analysis and recording software is used to record and analyze the test process and results, and the results are displayed in the comparison results curve of this experiment. In the simulation test result curve, the third-party analysis and recording software function is used to eliminate the uncertainty caused by simulation laboratory personnel operation and computer simulation equipment, and the retrieval capability is simulated in test only for different athletes and different data spatial trajectory retrieval methods. The comparison curve of the test results is shown in Fig. 3. Based on the experimental results curve, using third-party analysis and recording software, the data spatial trajectory retrieval method proposed in this paper and the retrieval ability of the conventional spatial trajectory retrieval method of athlete's motion data are arithmetically weighted, and the search ability of proposed trajectory retrieval is increased by 53.41%, compared with conventional trajectory search, which is suitable for detailed spatial trajectory retrieval of the athlete's stepping motion.

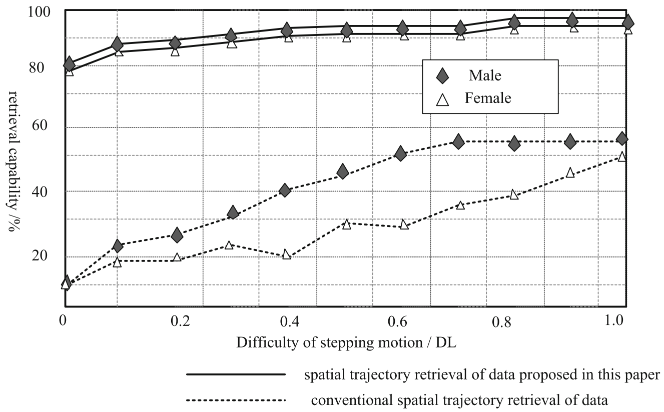

Fig. 3. Comparison curve of test results

6 Conclusion

The research on spatial trajectory retrieval method of athletes stepping motion data is proposed in this paper, based on the construction of spatial trajectory retrieval model of athletes stepping motion data, and design of spatial trajectory index of athletes stepping motion data, the research in this paper is completed. Experiment data show that the spatial trajectory retrieval method for data is highly effective. In the future research work, we will focus on the research of trajectory search efficiency. It is desired that the research in this paper can provide a theoretical basis for the data spatial trajectory retrieval method.

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