International Journal of Hybrid Information Technology
Vol.6, No.6 (2013), pp.31-40
http://dx.doi.org/10.14257/ijhit.2013.6.6.03

A New Quadtree Histogram-based Spatial Modeling based on Cloud Model

Zhaohui Wang
Qingdao Hotel Management College
wangzhaohui2010@126.com

Abstract

Spatial modeling is one of the most important parts in the area of spatial relations, and it is necessary to develop a new model with high practicality. Firstly this paper analyzes the characteristics and defects of present models; secondly introduces in detail the construction method of quadtree histogram; thirdly cloud model are used to judge spatial directional relation. The experimental results show that the model is feasible.

Keywords: *Quadtree Histogram; Cloud Model; Spatial Modeling; Directional Relation*

1. Introduction

Computer vision is concerned with automatic extraction of useful information from images. The description for human space perception is an important task of the computer vision research. The description of spatial relation is a basic ability of human cognition, it is an important basic task for computer audio-visual information processing to build automatically the description of spatial relation between objects in the image.

Spatial relation is mainly constituted of directional relation, topological relation and distance relation. The fundamental theories of topology relation and distance relation are comparatively perfect, but the fundamental theories of directional relation have not any unified standard. There are three main approaches for assessing the basic directional relation. The first one is based on cone model [1] which assimilates an object to the centroid, but it doesn't take into account shape, size and distance information. The second one is based on projection model such as minimum bounding rectangles [2], and directional relation matrix [3], *etc.*, but these models assimilate an object to the minimum bounding rectangle, so shape, size and distance information also can't be taken into account. The third one is based on angle-histogram model [4]. Given an object of target *A* and a reference object *B*, the angle-histogram is computed from the angles between any two points in both objects and normalized by the maximum frequency. This histogram represents the directional relations of the object *A* with respect to the reference object *B*. This model has taken into account shape, size and distance information. But this model has high computational complexity, so it is not practical. Numerous studies are based on this notion of angle-histogram, *e.g.*, [5-8]. In [5-7], R-histogram, R*-histogram and F-histogram are proposed, and they can reduce the computational complexity. In [8], a quadtree histogram model of spatial directional relation is proposed, and it can get high accuracy and small computational complexity together.

ISSN: 1738-9968 IJHIT

But all above approaches adopt fuzzy theory to judge directional relation. Fuzzy theory uses membership to quantificationally describe the double-sided property of objective things, however, it ignores the uncertainty of membership itself. Cloud model [9] combines fuzziness and randomness, and realizes natural transformation between the qualitative linguistic value and the quantitative numerical value.

Combining cloud model and quadtree histogram, this paper raises a new quadtree histogram model of spatial directional relation. This method doesn't only consider fuzziness of image processing, but also consider randomness of image processing.

2. Quadtree Histogram

The article [8] proposed quadtree histogram model which can get high accuracy and small computational complexity together. Based on the two factors affecting the integration of graphics, this article presents quadtree histogram. The main idea of the histogram includes three steps. Firstly the objects are divided into a number of simple and regular sub-objects using quadtree histogram arithmetic, so that these sub-objects can get the standard of integration to a point. Secondly, we use the centroids of these sub-objects instead of the sub-objects themselves. Thirdly, we calculate the weighted angle histogram of centroid point pairs.

1) The ratio of the side length of sub-square m to the side length of the minimum bounding square MBSAB of two objects M should be less than the threshold value σ_1.

2）The ratio of the area of the object in a sub-square to the area of the sub-square should be more than the threshold value σ_2 by formula (1).

$$\sigma_2 = \left(\frac{m}{\sigma_1 M}\right)^{\rho} \tag{1}$$

We can adjust the parameters σ_1 and ρ to control the division of the quadtree. Let $G_A = \{(g_1^A, \text{Area}_1^A), (g_2^A, \text{Area}_2^A), ..., (g_N^A, \text{Area}_N^A)\}$ and $G_B = \{(g_1^B, \text{Area}_1^B), (g_2^B, \text{Area}_2^B), ..., (g_M^B, \text{Area}_M^B)\}$ be the set of centroid of sub-squares covering object A and object B and their respective area of the object in the sub-square by formula (2) and formula (3). Let Area_A and Area_B be the area of object A and B, N and M be the number of the sub-squares MBS_A and sub-squares MBS_B, α_{ij} be the pairwise angle between g_i^A and g_j^B.

$$Area_i^A = Area_A \cap MBS_i^A \tag{2}$$

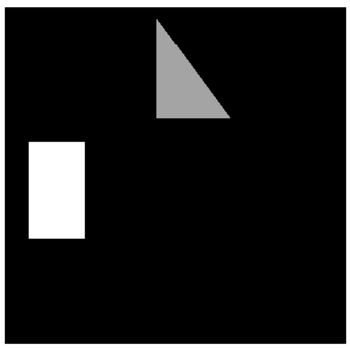
$$Area_j^B = Area_B \cap MBS_j^B \tag{3}$$

Once the set of sub-squares and their corresponding parameters are defined, we build the quadtree histogram by formula (4) and formula (5). Let τ be the step of quantization of the interval $[-\pi, \pi]$. We can adjust τ to handle the accuracy of histogram. In this paper, let τ be 1.

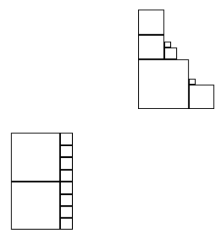
$$QH_\theta(A,B) = \begin{cases} +Area_i^A * Area_j^B & if \quad \alpha_{ij} \in [\theta - \frac{\tau}{2}, \theta + \frac{\tau}{2}] \\ 0 & else \end{cases} \tag{4}$$

$$QH_\theta(A,B) = \frac{QH_\theta(A,B)}{\sum_\theta QH_\theta(A,B)} \tag{5}$$

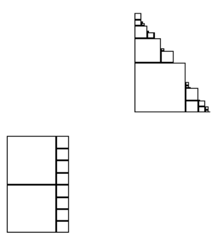
In article [8], it define σ_1=1/3 and ρ=1/3 in order to get high accuracy and small computational complexity together. They construct a graphics database of quadtree histogram (GDQH) for experiments, and it consists of 200 synthetic images of size 400×400 containing two objects with complicated or simple shape. They respectively generate angle-histogram and quadtree histogram as shown in Figure 1 for one image of GDQH in Figure 1(a) in C++ programming language on a Pentium 3.19 GHz PC with 2GB RAM. Figure 1(b), Figure 1(c) and Figure 1(d) respectively are the results of quadtree division with different values of σ_1 and ρ. Figure 1(f), Figure 1(g) and Figure 1(h) respectively are quadtree histograms with different values of σ_1 and ρ. These figures show that the smaller the values of σ_1 and ρ are, the higher the accuracy of division is, and the more similar the shapes of angle-histogram and quadtree histogram are. As $\sigma_1=1/M$, quadtree histogram is equal to angle-histogram. But Table 1 shows that the smaller the values of σ_1 and ρ are, the higher the computational complexity of quadtree histogram is.



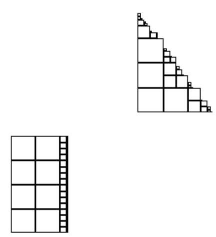
a) Original image



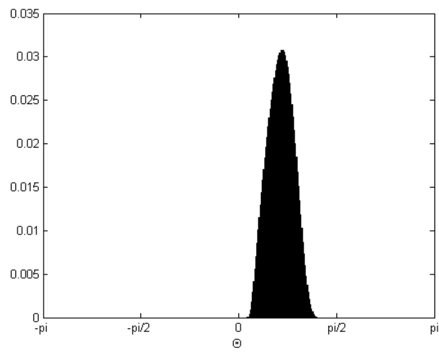
b) σ1=1/3 and ρ=1



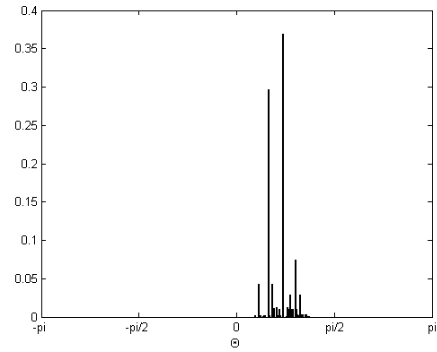
c) σ1=1/3 and ρ=1/3



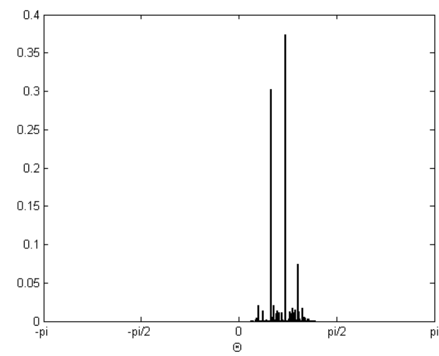
d) σ1=1/6 and ρ=1/3



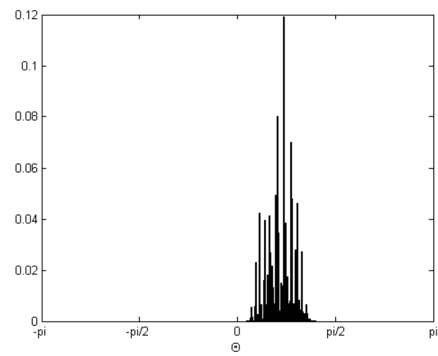
e) Angle-histogram



f) σ1=1/3 and ρ=1



g) σ1=1/3 and ρ=1/3



h) σ1=1/6 and ρ=1/3

Figure 1. Quadtree histogram

Table 1. CPU time

(s)	**Angle-histogram**	**σ_1=1/3 and ρ=1**	**σ_1=1/3 and ρ=1/3**	**σ_1=1/6 and ρ=1/3**
Time of CPU	3.258	0.008	0.011	0.023

3. Cloud model

Cloud model [9] is an uncertainty transformation model between a qualitative conception $\tilde{A}$ represented by natural linguistic value and the quantitative representation. U is an universe of discourse (one-dimension or multi-dimension) represented by exact numerical values. The qualitative conception $\tilde{A}$ relative to any element x of U has a random number y= $\mu_{\tilde{A}}$ (x), which has steady trend. Y is the certainty degree of x relative to $\tilde{A}$. The distribution of x in U is called cloud model, or cloud for short. Cloud consists of lots of cloud droplets, every droplet is a concrete realization of the qualitative conception in numerical domain, and this realization has the uncertainty.

The numerical characteristics of cloud consists of expectation (Ex), entropy (En) and hyper entropy(He). It combines fuzziness and randomness of linguistic value, and makes up of the mapping between qualitative conception and quantitative numerical value. Ex is the center of gravity of all cloud droplets in numerical domain, and reflects the coordinate in numerical domain, of which best represents the qualitative conception. En is a variable which describes the double-sided property of qualitative conception, reflects the range of numerical domain which can be accepted by the linguistic value, and reflects the probability that the points of numerical domain can represent the linguistic value. He is the discrete degree of En, called the entropy of entropy; it reflects condensation degree of every numerical value representing the linguistic value, as well as the condensation degree of cloud droplets.

The every branch of social science and natural science has proved the universality of normal distribution [10]. Therefore, normal cloud becomes the most basal cloud; it is the most useful to represent basic linguistic value (linguistic atom) of natural language. In this paper all clouds adopted are normal cloud.

Cloud generator (CG) is the model which can generate cloud; its kinds contain normal cloud generator, backward cloud generator, X condition cloud generator and Y condition cloud generator [11].

When the three numerical characteristics and the number N of droplets are fixed, a cloud can be generated by CG. For example, Ex=0, En=1,He=0.05,N=2000, a cloud can be seen on Figure 2.

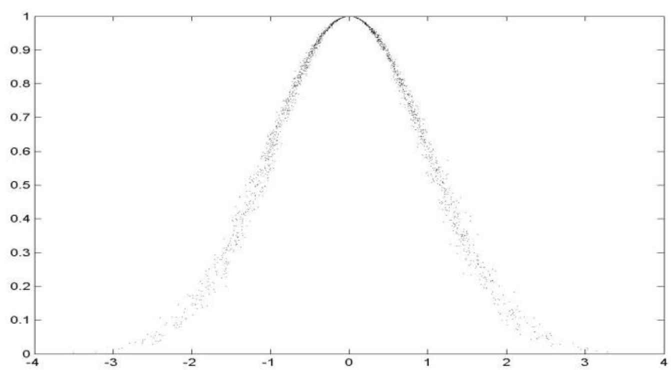


Figure 2. Cloud of CG(0,1,0.05)

When the three numerical characteristics are fixed and x= x_0, the cloud droplets (x_0, y_i) are called X condition cloud. When the three numerical characteristics are fixed and y= μ_0, the cloud droplets (x_i, μ_0) are called Y condition cloud. The CG which can generates X cloud or Y cloud is called X-CG or Y-CG.

4. The Quadtree Histogram Model of Spatial Directional Relation based on Cloud Model

In order to judge the spatial directional relation based on quadtree histogram, we usually use the arithmetic mean method (K) and the compatibility method (M). The K method uses Formula (6) and membership functions in Figure 3 to calculate the gravity of membership degrees of all directions on the distribution of θ, to determine primary direction and secondary direction between objects by comparing the value of membership degrees.

$$\mu = \sum_{\theta} \mu_{\text{left}}(\theta) f(\theta) \tag{6}$$

The K method treats the histogram as an unlabeled fuzzy set, which captures "the spatial directional relation between A and B".

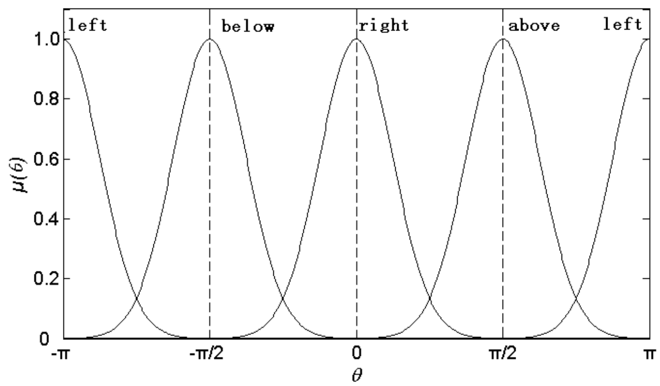


Figure 3. Membership functions of four directions

The M method also regards histogram as a fuzzy set. Given the fuzzy sets "right", "left", "above" and "below" the degree to which QH is each of these spatial relations is obtained using the compatibility operation of a distribution to a fuzzy set. According to the compatibility of a distribution F to a fuzzy set G is the extension of evaluation of a fuzzy set in a point to a fuzzy set; the result is a fuzzy set CP(F; G) whose membership function $\mu_{\text{CP}(F;G)}^{\text{VH}} : [0,1] \rightarrow [0,1]$ is obtained by the extension principle Formula (7). In our method F is the histogram QH and G is the fuzzy R, associated to a spatial directional relation, as shown in Figure 3. The final membership degree of spatial directional relation is obtained as center of gravity of the compatibility fuzzy set by Formula (8). Finally, the M method determines primary direction and secondary direction between objects by comparing the value of membership degrees as the K method.

$$\mu_{\text{CP}(F;\text{left})}^{\text{QH}}(v) = \begin{cases} \sup\limits_{s, v=\mu_{\text{left}}(s)} \mu_F(s) & \\ 0 & \text{if} \quad \mu_{\text{left}}^{-1}(v) = \phi \end{cases} \tag{7}$$

$$\mu_{\text{left}}^{\text{QH}} = \int_{0<v\leq 1} (v \mu_{\text{CP}(F;\text{left})}^{\text{QH}}(v)) dv \tag{8}$$

In this paper, we use cloud membership function instead of fuzzy membership function. We use four X condition cloud generator for inputs. 'left' has numerical characteristics (-π, π/8, π/24), 'below' has numerical characteristics (-π/2, π/8, π/24), 'right' has numerical characteristics (0, π/8, π/24), 'above' has numerical characteristics (π/2, π/8, π/24). So the K and M methods become K Cloud and M Cloud Methods.

5. Experimental Results

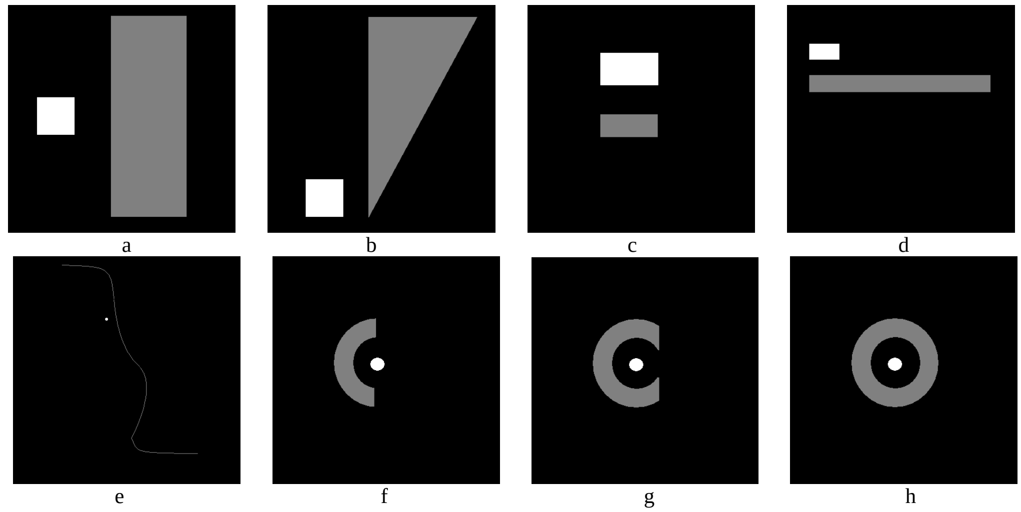


Figure 4. Examples

We respectively use four methods K, M, K Cloud and M Cloud to judge the spatial directional relation of eight synthetic images of size 400×400 containing two objects with complicated shape in Figure 4. The results are shown in Table 2. These methods base on quadtree histogram. To determine a method whether good, we can use the notion of directional relation to analyze the characteristic of judging directional relation with every case (K, M, KC and MC) in the non-specific application.

Table 2. Results of the directional relation

(%)	a				b				c				d			
	K	**KC**	**M**	**MC**	**K**	**KC**	**M**	**MC**	**K**	**KC**	**M**	**MC**	**K**	**KC**	**M**	**MC**
Right	76	72	82	78	26	29	34	38	9	8	16	13	76	78	82	80
Above	12	15	25	23	71	68	79	82	0	1	0	2	0	3	0	2
Left	0	3	0	3	0	4	0	4	9	10	16	16	3	4	18	20
Down	12	9	25	27	3	7	11	7	82	79	92	95	21	19	43	41

(%)	e				f				g				h			
	K	**KC**	**M**	**MC**	**K**	**KC**	**M**	**MC**	**K**	**KC**	**M**	**MC**	**K**	**KC**	**M**	**MC**
Right	22	26	23	25	0	2	0	1	7	5	15	13	25	23	50	48
Above	39	35	89	85	23	24	49	51	24	23	50	52	25	24	50	53
Left	3	4	7	3	54	52	57	54	45	46	50	51	25	26	50	52
Down	36	38	83	89	23	23	49	47	24	21	50	49	25	27	50	51

We can see that the results based on KC method and MC methods are the same of K method and M method, and the values only have a few differences. We can see the judgment results can be basically consistent with human cognition. So KC is the same of K method, and MC is the same of M method.

But there are some differences between KC and K method (MC and M method). The result values have a few differences, because the cloud model considers the randomness. This randomness can represent the different cognitions of different people for directional relation. For example, the judgment results of K and M assign degree values to the four directions, but the judgments of K and M are possibly different from human cognition. Take Figure 4(e) for example, the judgments of K and M is “primary direction is above”, but the judgment of human may be “primary direction is down”. Because in Figure 4(e) “above” and “down” can easily be confused, different people may be consider the primary direction is “above” or “down”. We realize the judgment of directional relation has randomness. The judgment results of KC and MC is “primary direction is down”, but when we did this experiment again, we could get different results. So we can say KC and MC methods can consider the randomness of directional relation, these methods can get the actual judgment results.

6. Conclusions

In this paper, a formal model of directional relation based on quadtree histogram and cloud model is introduced. Firstly, we introduce the quadtree histogram which inherits the characteristics of angle histogram. The quadtree histogram can fully take into account the effects of shape, size and distance information to judging directional relation, and it can also ensure high accuracy and low complexity. Secondly, we use the arithmetic mean method based on cloud model and the compatibility method based on cloud model to judge spatial directional relation. These methods don’t only consider fuzziness of directional relation judgment, but also consider randomness. The judgment results can be basically consistent with human cognition.

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Authors

Zhaohui Wang received the Bachelor degree in Computer Engineering from Qingdao Technological University and Master's degree in Computer Engineering from China Ocean University,CHINA in 2004 and 2008 respectively.She is currently teaching at Hotel Management College.She is currently researching Spatial modeling, onImage Processing and Pattern Recognition.