Buffer analysis of 3D underground pipe network

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Abstract： With the digital city and smart city building, as a geographical information system of urban underground pipe network has become one of the hottest urban lifeline nowadays research. In this paper, 3D visualization of the underground pipe network GIS background, 3D study of the underground pipe network GIS buffer analysis, solving the 3D network of GIS spatial proximity problems. Proposed based on the 3D vector analysis of the buffer, and the introduction of space vector overlay network based on GIS and spatial data special attributes, solving the 3D network buffers. And describes the analysis of 3D network buffer tube to the pipe network location, the scope of the accident, pipeline maintenance decision support provided.

Keywords: urban underground pipe network, GIS, spatial analysis, buffer analysis, spatial overlay

Introduction

Urban underground pipe network as a city upon which the survival and development of infrastructure, undertakes the important task of energy supply, information transmission, and the people's production and daily life. The need for the establishment of urban underground pipe network information system is already becoming more urgent, now more than in urban areas and abroad have established their 2D or 3D underground pipe network GIS for urban planning, to form urban construction efficient management and decision support. However, the traditional network management system has a poor performance space, spatial query and analysis capabilities, such as the lack of limitations, so this 3D underground pipe network for GIS buffer analysis system to do a study to solve the problem of spatial proximity the degree with 3D pipe network in GIS.

Buffer analysis in the 2D concept of research has closed to matured, such as "based on a buffer raster and vector analysis algorithm combines the research" by Ronggui Li et al, comparing the GIS buffer analysis of the advantages and disadvantages of two commonly algorithms, then propose a buffer analysis algorithm based on combines grid and vector, it can correctly handle variety situations such as self-intersection [1]; Shuang Cui, who put forward the "buffer space object based analysis algorithm" use space objects as the size of

calculation, solve the difficult to handle within space entity granularity problem analysis by the traditional buffer analysis[2].

However, With the development of smart city building, 2D concept of buffer analysis forward can't satisfied the need of the 3D visualization of spatial analysis, therefore research GIS buffer analysis of 3D space is more important than before. " Based on the highly effective Boolean operation of 3D vector buffer algorithm " proposed by Xinming Lu, the algorithm to achieve effective for solving the 3D vector space object buffer [3]; Hua Qiu's, "3D data generation and the analysis of buffer " Using the Euclidean distance transform method of 3D signed realize 3 d buffer analysis [4]. This paper will focus on 3D GIS of underground pipe network system of buffer analysis propose a convenient solution ,by the way, realized and analyzed this solution.

1. buffer analysis

Definition 1: based on the concept of proximity, establishment of buffer can put the map into two areas: one area is located within a specified distance from the selected map features; another area for a specified distance away. Area within a specified distance called buffer [5].

Definition 2: Buffer refers scope of influence or range of services to a geospatial target[6].

Definition 3: in the specific area, given a distance r, the entire region of the 3D object distance d is less than r is called the 3D object o's buffer: $B = \{p: d(p, o) \leq r\}$

Where in B represents a 3D buffer, o represents the original object itself, d (p, o) represents the distance from an element in the buffer zone to the original object, and p is an element of the buffer zone, r represents the given distance value [7].

The basic elements of 3D GIS spatial analysis are four aspects: point, line, surface and body, therefore 3D buffer analysis can be divided into point buffer, line buffer, the buffer surface, body buffer.

1.1Buffer Analysis of Spatial Point

In the 3D space, spatial point buffer is space regional for the center of the sphere as point, the buffer distance is the radius of the sphere. the space regional is the point of buffer space. spatial point $o(x_0, y_0, z_0)$buffer is: $B=\{p:d(p,o)<r\}$, to achieve a 3D point of buffer space, only need to draw out the buffer surface, need to solve sphere surface point $[x,y,z]=\{((x,y,z):(x-x_0)^2+(y-y_0)^2+(z-z_0)^2)^1/2=r\}$, set of surface points (x, y, z) to form a continuous triangular surfaces to generate a buffer surface, achieve 3D visualization(Figure 1).

Algorithm of spatial point (x0, y0, z0) generated sphere is:

Step 1 in the plane which parallel to the XOY, $z=z_0$,use plane point (x_0, y_0) as the center, the buffer distance r as radiusthengeneratedsemicircle, evenly distributed on the circumference of the n / 2 + 1 coordinate points, generating $\{P_1, P_2,\ldots, P_{n/2}, P_{n/2+1}\}$of the set of points.

Step2 use P1 to Pn /2 + 1 as axis, to the point set$\{P_1, P_2,\ldots, P_{n/2}, P_{n/2+1}\}$use 360° /n as rotation angle, rotation n times, thereby generating sphere point set.

Step3according to the corresponding relationship between the points, connected the set of points into a continuous even surface, all points and continuous surface consisting of a spherical surface, both for spatial point buffer surface[3].

Point buffer(point generating spherical) algorithm is as follows:

pointbuffer(x_0,y_0,z_0,n)

for(i=1;i<=(n/2+1);i++){

theta=(360/n)*3.14/180; // calculating the Central angle which circumference

px_i=r*sin(i*theta)+x_0; py_i=r*cos(i*theta)+y_0;// generated semicircle n/2+1 coordinate points use the buffer distance r as radiusat

p_i=p_i-p_1 // move the starting point of The rotary shaft to the coordinates origin, corresponding movement of the other points;

for（j=1;j<=n;j++){

$x= (px_{n/2+1}- px_1)/ ((px_{n/2+1}- px_1)^2+(py_{n/2+1}- py_{12})^2+(pz_{n/2+1}- pz_1)^2)^{1/2}$

$y=(py_{n/2+1}- py_1) / ((px_{n/2+1}- px_1)^2+(py_{n/2+1}- py_{12})^2+(pz_{n/2+1}- pz_1)^2)^{1/2}$

$z=(pz_{n/2+1}- pz_1) / ((px_{n/2+1}- px_1)^2+(py_{n/2+1}- py_{12})^2+(pz_{n/2+1}- pz_1)^2)^{1/2}$

// Solving unit vector of the rotation axis

gamma=(360/n)*3.14/180;// Angle of rotation

c = j*cos(gamma)；s = j*sin(gamma)；

$px_{i,j}=(x^2(1-c)+c) * px_i + (xy(1-c)-zs) * py_i + (xz(1-c)+ys) * pz_i+ p_1$

$py_{i,j}=(yx(1-c)+zs) * px_i + (y^2(1-c)+c) * py_i + (yz(1-c)-xs)* pz_i+ p_1$

$py_{i,j}=(xz(1-c)-ys) * px_i+(yz(1-c)+ xs) * py_i + (z^2(1-c)+c)* pz_i+ p_1$

//Solving the rotated coordinates, original coordinate take a left multiply to the rotation matrix, then move reverse the coordinates to the correct position}}

// connected the set of points into a continuous even triangle surface

for(i=1;i<=n/2;i++){

for(j=1;j<n;j++){

line($p_{i,j}$,$p_{i+1,j}$);line($p_{i,j}$,$p_{i+1,j+1}$);line($p_{i,j}$,$p_{i,j+1}$);}

line($p_{i,n}$,$p_{i+1,n}$);line($p_{i,n}$,$p_{i+1,1}$);line($p_{i,n}$,$p_{i,1}$);}// Connected circle start and endpoint

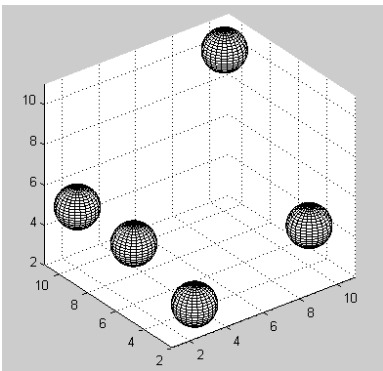


Figure 1. The point buffer space

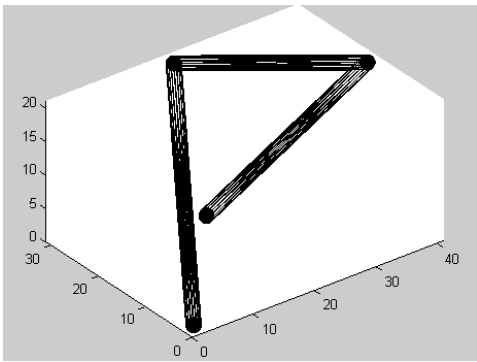


Figure 2. Buffer Analysis of Spatial edge

1.2 Buffer Analysis of Spatial edge

Spatial edge is composed of two end points and connections, namely edge buffer analysis can be seen as super position the end point buffer(sphere) and the central axis line of the cylinder. $P_1(x_1, y_1, z_1)$, $P_2(x_2, y_2, z_2)$connection l's buffer is: $L=\{l: d(l, o)\leq r\} \cup B_1 \cup B_2$where in B_1 and B_2 as point buffer of $P_1$and P_2(Figure 2),buffer algorithm is:

Step1 Assume P_1 and $P_2$for the edge of endpoints, by1.1point buffer analysis to generate buffer space of P_1 and P_2, connected P_1 and P_2 as axis, the axial direction of the vector$\mathbf{V_1}$.

Step2 use P_1as circle center located in the plane which perpendicular to$\mathbf{V_1}$,generating radius is r, the number of edge s of the circumference, recording the coordinates of the n points on the circumference

Step3 in a similar way, use P_2as circle center located in the plane which perpendicular to$\mathbf{V_1}$, generating radius is r, the number of edges of the circumference, recording the coordinates of the n points on the circumference.

Step4 connecting points on the two circumference, generate the cylindrical surface. two endpoints formed circumferential surface and the cylindrical surface formed the edge of the buffer cylinder.

Step 5 use the cylinder and ball handling spatial overlay that intersection operations.

Sideline generate buffer (two point generating cylindrical surface) algorithm is as follows:

linebuffer(x_1,y_1,z_1, x_2,y_2,z_2,n)

for(i=1;i<=n;i++);{

θ=(360/n)*3.14/180; nx=x_2-x_1 /((x_2-x_1)^2+(y_2-y_1)^2+(z_2-z_1)^2)$^{1/2}$;

ny=y_2-y_1 /((x_2-x_1)^2+(y_2-y_1)^2+(z_2-z_1)^2)$^{1/2}$; nz=y_2-y_1 /((x_2-x_1)^2+(y_2-y_1)^2+(z_2-z_1)^2)$^{1/2}$;

// Solving plane unit normal vector **V** of the circle

ux=ny/((nx^2+ny^2)$^{1/2}$);uy=-nx/((nx^2+ny^2)$^{1/2}$);uz=0;// Plane vector U

vx=nx*nz/((nx*nz)^2+(ny*nz)^2+(-nx^2-ny^2)^2)$^{1/2}$;vy=ny*nz/((nx*nz)^2+(ny*nz)^2+(-nx^2-ny^2)^2)$^{1/2}$;vz=(-nx^2-ny^2)/((nx*nz)^2+(ny*nz)^2 + (-nx^2-ny^2)^2)$^{1/2}$;// Solution M orthogonal unit vectors **M** of **U** and **V**

$x1_i$=px_1+r*(ux*cos(θ)+vx*sin(θ));$y1_i$=py_1+r*(uy*cos(θ)+vy*sin(θ));$z1_i$=pz_1+r*(uz*cos(θ)+vz*sin(θ));}// Generate circumference point

Similarly generation x2,y2,z2;

// connected the set of points into a continuous even triangle surface

for(i=1;i<n;i++){

line($x1_i$,$y1_i$,$z1_i$,$x2_i$,$y2_i$,$z2_i$);line($x1_i$,$y1_i$,$z1_i$,$x2_{i+1}$,$y2_{i+1}$,$z2_{i+1}$);line($x1_i$,$y1_i$,$z1_i$,$x1_{i+1}$,$y1_{i+1}$,$z1_{i+1}$);}

line($x1_n$,$y1_n$,$z1_n$,$x2_n$,$y2_n$,$z2_n$);line($x1_n$,$y1_n$,$z1_n$,$x2_1$,$y2_1$,$z2_1$);line($x1_n$,$y1_n$,$z1_n$,$x1_1$,$y1_1$,$z1_1$);}

// Connected circle start and endpoint

1.3 Body and surface buffer analysis

3D space surface buffer analysis can be seen as superposition a edge buffer which consisting of surface and surface stretch along the normal vector direction. 3D space in the body buffer analysis can be seen as the superposition the 3D space of the body surface buffer.

2. Buffer analysis of 3D underground pipe network

3D pipe network is a directed network 3D coordinate to the network, data information storage use 3D point coordinate and the radius of the pipe, Section of the pipe network can be represented as several successive nodes pipes and nodes. Therefore, the 3D network of buffer analysis can be divided into two parts, pipe section between the node and the node, and the node (water wells, valves, two-way, three-way, four-way nodes).

3D point buffer is the sphere that point target for centre of sphere, a certain distance of the sphere radius. For valves, three nodes, four nodes, the nodes of the buffer wells can be simplified to the point of the buffer: $B_i=\{p_i:d(p_i, o) \leq r+r_0\}$

Where r_0 is the largest of distance from the center of the node to the outer surface of the node.

Line buffer analysis can be seen as a collection of numerous point buffer. in the underground pipe network, you can simplify the pipeline for the line, that line can be seen as a buffer that line width as the diameter of pipe network, line l (centerline as a starting point (x_0, y_0, z_0) to the next node (x_1, y_1, z_1) of the line segment) of the buffer can be defined as: $L=\{l : d(l, o) \leq r+r_1\} \cup B_0 \cup B_1$. there into $\{l: d(l, o) \leq r+r_1\}$is the cylinder that the centerline L is the pipeline's centerline, the radius is pipeline radius $r+r_1$, r_1 represents the shortest distance between pipeline's centerline to the outer wall of the tube, r is the distance buffer. so pipe line buffer can be simplified as and operation with spheres and cylinders [10].

3. 3D network buffer analysis algorithm:

3D network buffers vector-based analysis algorithm will be broken down into the path selection, calculate nodes buffer calculate network cable buffer, the buffer stack through spatial database topological relationships. 3D network buffer analysis, for example, use two adjacent nodes $P_1(x_0, y_0, z_0)$, $P_2(x_1, y_1, z_1)$, buffer is: $B=\{p_0:d(p_0, o) \leq r+r_0\} \cup \{p_1:d(p_1, o) \leq r+r_0\} \cup \{l: d(l, o) \leq r+r_1\}$(Figure3).The algorithm is as follows:

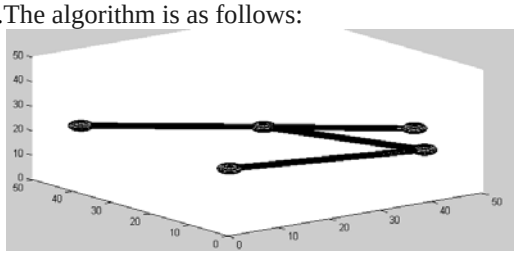


Figure 3. The 3D pipe network buffers

Step 1: calculate the buffer area central node （x_{i0}，y_{i0}，z_{i0}）, where, i represents of the same category of pipeline, such as heat pipes;

Step 2: From the central node structure analysis path, generating space tree, where the central node is the root node, adjacent node as a child node [8];

Step 3: Calculate the buffer of each node, return buffer range: $B_{ij}=\{x_j:d(x_j, o) \leq r+r_0\}$;

Step 4: Calculate the various sections of the buffer, calculated sideline root buffer and leaf nodes buffer, return buffer range: $L_{ij}=\{l_{ij} : d(l_{ij}, o) \leq r+r_0\} \cup B_{i0} \cup B_{i0}\}$;

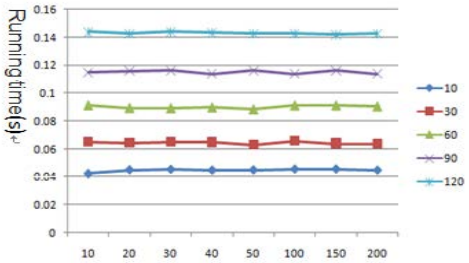
Step 5: overlay the nodes buffer and edges buffer, that are intersection operation of the sphere and cylinder, generating pipeline i's buffer

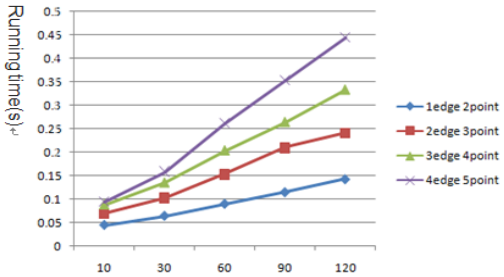
Step 6: Repeat steps 1 through steps 5, calculate different kind of pipeline buffers;

Step 7: overlay different pipeline buffers.

4. The pipe network buffer algorithm analysis

For the vector-base of buffer algorithm, compared to grid-based buffer algorithm, the running time has obvious advantages, experiments show that: vector-base of buffer algorithm, the running time is independent of the size of the buffer radius. follows table under the same distribution points (algorithm distributed over the cross-sectional circle point n), different buffers radii, run times are the same(Figure 4). Unlike the algorithm based on raster buffer, following the buffer radius increasing, the calculation time is also a corresponding increase.





Buffer radius (cm)

Figure 4.Relationship between the efficiency of the algorithm with the radius of the buffer

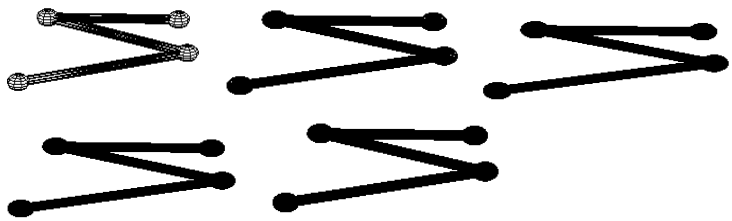
Sectional point n distributed on the circle

Figure 5. The relationship between

algorithm efficiency of the different point and edges with n

Buffer visualization algorithms vector-based in a 3D pipe network, with the increase of a given number of nodes and the number of edges, the running time of the algorithm increases. (Figure4 and 5) Therefore, when we calculation of a certain area pipe network the buffer is needed to determine in advance of this charge of network data (points, lines), reduce unnecessary calculation brings efficiencies to reduce the problem. Under the premise of the edge points in the pipe is determined when network, the buffer algorithm efficiency is connected with point distributed on the surface of the pipe network, in the algorithm, as n increases, algorithm for computing time rises in a straight line. the number of round cross section to determine the number of points n.

Therefore, when implemented the 3D buffer, it is need to select the appropriate n in order to ensure operational efficiency and visualization, in order to ensure. In Figure 6 4:03 sides Case line buffer to achieve, n = 10, the too sparse, but when n> 30, the visual effect is basically unchanged, so you can choose n between 30 to 10 in order to improve the efficiency of the algorithm(Figure 6).



(a).n=10 (b).n=30 (c).n=60 (d).n=90 (d).n=120

Figure 6. Comparison of different buffer under distribution points

5 Pipe network buffer analysis applications:

5.1 Pipe network site selection

When the pipe network layout, a new pipeline for the determined optimal path, consider the new pipeline on the existing network, the existing network must have given buffer arear$_1$ (wherein r_1 is the safe distance for existing pipe and new pipeline), Get the pipe line buffer according to the pipeline radius r and the pipeline node central coordinate; Detection of new and existing pipeline network buffer has inter section, if it have intersection you need to change the new pipeline route(premise without changing the original pipe network shape) ,.until there have no joint position with the new pipeline and the existing pipeline buffer.

5.2 determine the sphere of influence

In the event of network failure, such as burst pipes, valves failures and other accidents, resulting in the pipe carrier leaks, you can know area of influence according to the pipeline attribute information, the reason of the accident and occurred qualification time given certainly, given the accident dimensional pipeline buffer in 3D scene to see if there is an adjacent pipelines is cover, if any, need for timely feedback of information, convenient with the deal. Meanwhile, overlay the pipeline buffer and infrastructure 3D scene, review and

statistical affected ground attachments in a 3D scene(such as: building, green belts, etc.), in order to assess the economic loss and the subsequent reconstruction work given reference.

5.3 Network Maintenance

In the past, because information imperfect , resource can't be shared and detection system is not popular in pipe network maintenance, makes the pipe network maintenance difficulties, for example difficulty to find the leak points, Dig a broken of other types of pipeline, make a large maintenance work or serious social impact.

Before the pipe network maintenance, after determining the service area, find the maintenance of the pipeline in the 3D scene, determine the pipeline buffer according to the attribute information and adjacent pipeline(within safe construction distance) attribute information of this pipeline. After confirming the buffer, overlay the basic geographic model and buffer then determine the needs of the construction site and earth work excavation required.

Conclusion:

3D pipe network spatial analysis, buffer analysis in the pipe network site selection can be given to visually decision support, and it can avoid new and existing pipeline network conflicts. Also, the 3D buffer analysis for decision-making support for emergency treatment. Achieve Vector-based 3D pipeline buffer analysis, and proposed to achieve a buffer analysis by overlay processing of3D pipe network by studying buffer of spatial point, line, face, body. The next step will be to refine spatial overlay algorithms to better achieve the 3D network of buffer analysis.

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