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Research on a New Three-dimension Reconstruction and Visualization Technology of Concrete Based on CT Images

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Abstract

In recent years, the research of concrete based on CT Images has been popular. A new modified Ray-casting on VTK aims to solve the poor effect on 3-D reconstruction of concrete CT image, which has great influence on the construction of accurate 3-D meso-concrete numerical model. Owing to this result, A new tech-VTK system came into being to get improvement and development. What is more, it can achieve visualization. It is tested that the method in this dissertation is more effective and accurate meanwhile it will help to build the construction of concrete material numerical model.

Keywords: *concrete CT image; three-dimension reconstruction; modified Ray-casting; VTK*

1. Introduction

Concrete is a kind of special natural defect materials which is formed with the grading aggregate, cement, mortar, pore and, *etc*., it has a complex internal structure, a multi-scale and unique physical and mechanical properties. As a heterogeneous material it is widely used in construction industry. In recent years, the X-ray CT testing of concrete becomes a hot research topic during meso-fracture process of concrete and rock material. The advantages of X-ray CT observation concrete crack evolution process is nondestructive detection performance and high resolution, and CT can directly observe the internal structure and the physical change of the materials during test. Now more and more researchers are used to study of concrete, rock meso-structure and fracture by X-ray CT. At present the research on concrete and rock based on CT images mainly focused on 2-D meso-concrete [1, 2].

3-D reconstruction is an important research field of visualized computer [4]. 3D reconstruction of Concrete CT studies for establishment of accurate finite element numerical meso-structure model of concrete material has an important reference meaning. For 3-D reconstruction on concrete CT images, mainly is used with MATLAB and MIMIC software [3]. The result of 3-D reconstruction is existing overproduction, and often under the condition of single hardware that its calculation cannot meet. So the reconstruction result can not truly study the real concrete meso-structure. The author specially research concrete CT images 3-D reconstruction by image processing and tech-VTK. A new modified Ray-casting algorithm

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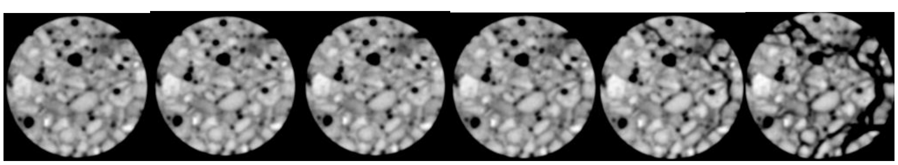
used in 3D reconstruction of concrete CT image is put forward. And the visualization system is realized, that provides an auxiliary method for real meso-structure numerical model of concrete.

2. Concrete CT image

The test specimen is cylinder, height 120mm, diameter 60mm. Cement intensity is C15, the Water and ash ratio for test specimen is 0.50. The aggregate is composed of artificially granite by the left Dadu river, and conserve 28d in standard condition. The test adopt PHILIPS brilliance 16 row helical CT scanner of second affiliated hospital of SanXia university, The scanning image distinguish of ratio is 512× 512. Figure 1 is the CT test panoramic views of test.The Loading equipment that professor Dan faning research group developed can apply to concrete, rock type materials of micromechanics experimental study. The test uses load control technique, load rate is 0,1kN/s, and scanning 10 times. CT machine Settings scanning parameters: 140kV voltage, 250mA current, thick layer of 0.5 mm, 5mm lamellar spacing. Figure 2 is a concrete section under different stress.

Figure 1. CT and loading equipment



(a)σ=0.00MPa (b)σ=21.23MPa (c)σ=27.24MPa (d)σ=36.08MPa (e)σ=32.22MPa (f)σ=12.7MPa

Figure 2. Stress of concrete

3. Modified Ray-casting Algorithm

Modified Ray-casting algorithm [5] is the most commonly used in direct volume rendering algorithm of typical image space order. The basic idea is: according to the direction of the line of sight, from each pixel of screen, sent a ray. Along the ray to sample according to certain step length of 3D data field, and through eight voxel attributes that are close to sample point calculate sample point attribute(color value and opacity value) by tri-linear interpolation method. For each sample point attribute values synthesis can accord back to front or front to back order, and generate display image from color value and opacity value of the pixel on the screen. Figure 3 shows the procedures of this algorithm.

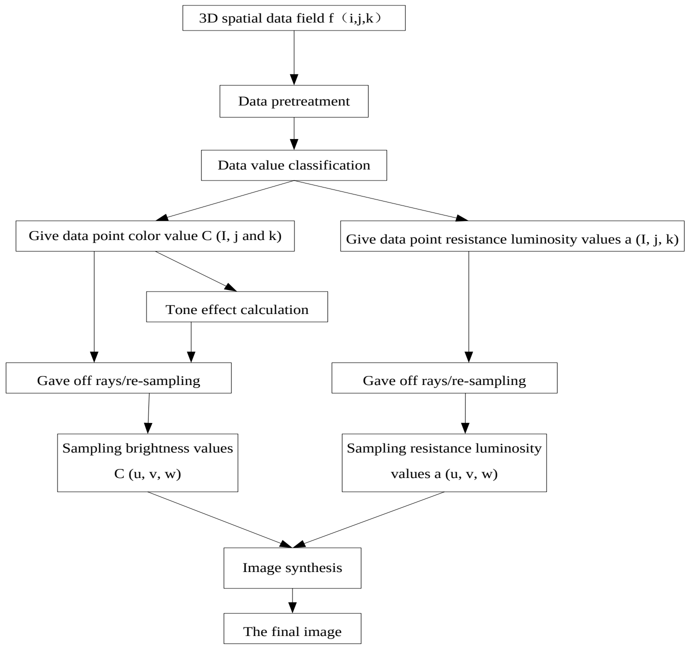


Figure 3. Flow chart of Ray-casting

The advantage of modified Ray-casting is mapped image has a high quality. However, modified Ray-casting need to randomized retrieval the data in the 3D data field, it involves a large the volume of data. In addition people's view direction is arbitrary, these will cause vision and voxel by any of intersect angle and the direction. When doing intersection operation of each light and voxel, it needs to traverse all the voxel, thus that need to send of each rays of sampling many times. All these will lead to computing is a large amount of calculation, and the speed of drawn image is also slowed. If the parameters with view-dependent have any change, the image should be redraw. In such cases, we would have to spend a lot of time to recalculate sample point position and color and transparency value, that equivalently to do many useless works. The rendering speed significantly reduced, and can't meet the software development requirement of real-time.

3.1. Data preprocessing optimization

Algorithm process is as follows:

First, calculating of planar convex set of the y coordinates of all points, the y value of the minimum point denoted as $p_{1.}$ p_1 with all the remaining points of convex set were connected to form a line. The angle between the line and the horizontal line is then calculated. Sorted by angle, if the same angle according to the distance between p and $p_1$sequencing. Sequence points are connected to the p_1, p_2, ...p_n, resulting in the formation of a polygon. Because p_1 is a starting point of convex hull, so p_2 and p_n is also a vertex of convex hull.

Second, Judging whether the two points are on the same side of a designated line or not. segment If two points in the same side of a designated line, deleted not the vertices of convex hull point from p_3 to p_{n-1}.

Finally, output the vertex of the convex hull.

3.2. Ray-casting voxel and re-sampling optimization

Assumption OUVW is image space coordinates, OXYZ is object space coordinates. Through casting polygon scan conversion we recorded the image Effective Pixels position in OUVW, and convert image space coordinates to object space coordinates. R indicates rotation matrix, T indicates translation matrix, then we can assume from the image space coordinate conversion of objects space coordinate matrix is $M=R*T$.

$$\mathrm{R}=\begin{pmatrix} r_0 & r_1 & r_2 & 0 \\ r_3 & r_4 & r_4 & 0 \\ r_6 & r_7 & r_8 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad \mathrm{T}=\begin{pmatrix} 1 & 0 & 0 & t_1 \\ 0 & 1 & 0 & t_2 \\ 0 & 0 & 1 & t_3 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

In coordinate transformation process we can use the correlation between the coordinates to optimizing. From iterative equation of correlation, the operation of coordinate transformation is reduced. Implementation is as follows:

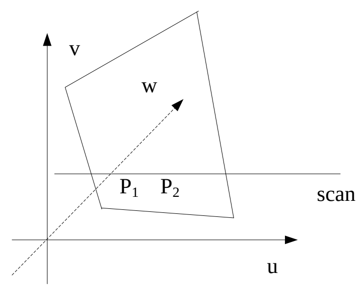


Figure 4. Plane of border upon pixels

In Figure 4, $p_1$coordinate is (u_1,v_1,w_1), p_2 coordinates is (u_2,v_2,w_2), p_1 and p_2 are adjacent pixels and both of them located in the same scan lines of image space coordinate. Because p_1 and p_2 exists correlativity, so p_2 also can be expressed as $(p_1.u+1,\ p_1.v,\ p_1.w)$ And you can use the following iterative equation to transformation the coordinate of p_2 to object space coordinates.

$$\begin{aligned} p_2^{'}.x &= p_2.x + r_0 \\ p_2^{'}.y &= p_2.y + r_3 \\ p_2^{'}.z &= p_2.z + r_6 \end{aligned} \qquad \textbf{(1)}$$

$(p_2.x, p_2.y, p_2.z)$ is the point p_1 in object space coordinates corresponding point $p_1^{'}$ coordinates. Through such iterative process, the computation of the coordinate transformation more reduce than it of the ordinary matrix before, and multiplication and addition operation reduced 9 times and 12 times, which greatly improves rendering speed. All pixels in the same scan lines can be calculated by coordinates transformation.

According to sight direction, using the bounding box of volume data field, we can fast calculate the starting point and the ending point of the cast light and 3D volume data field. This step is decrease sampling. In the process of intersection, we only need to consider the intersections of the light and the six surfaces $M_1;M_2;\mathrm{L}\ ;M_6$ bounding of cuboids box.

$$M_1 = \min_x \times \Delta x \qquad M_2 = \max_x \times \Delta x;$$
$$M_3 = \min_y \times \Delta y \qquad M_4 = \max_y \times \Delta y; \qquad (2)$$
$$M_5 = \min_z \times \Delta z \qquad M_6 = \max_z \times \Delta z;$$

Because of the incident ray direction is arbitrary, it have three kinds of cases with cuboids bounding box at the intersection point: 1. The intersection point falls in the inside of surface cuboids; 2. The intersection point falls in the inner of cuboids; 3. The intersection point falls in vertex of cuboids. If the two intersection points coincide, the screen pixel color of light is set to background color value. Otherwise it need to use the direction of the light sorting the two intersection points, and then confirming the in and out points.

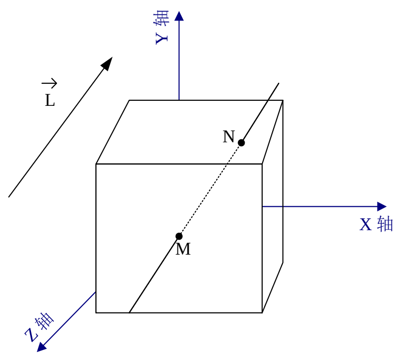


Figure 5. Two intersection pixels taxis

As the Figure 5 shows, we hypothesized that $M(x_M,y_M,z_M)$ and $N(x_N,y_N,z_N)$ is the two intersects of the current incident ray and cuboid bounding Box. $\vec{L} = (x_L, y_L, z_L)$ shows the casting light direction, and it is not zero vector. Sort the M and N to determining the in and out points. First we might hypothesis the point M is the in point while N is the out one. The vector $\vec{l} = (x_l, y_l, z_l)$ from the in point to the out one has a relationship to the vector $\vec{L}$ of casting light: $\vec{l} = \lambda \vec{L}(\lambda > 0)$. That meanings to judge whether vector $\vec{MN} = (x_N - x_M, y_N - y_M, z_N - z_M)$ coincidental with vector $\vec{L}$. This paper adopts appropriate function signs (x) to judge:

$$sign(x) = \begin{cases} 1 \ \ if\ x > 0 \\ -1 if\ x < 0 \\ 0 \ \ if\ x = 0 \end{cases} \qquad (3)$$

To find the three nonzero vectors from vector $\vec{MN}$. We might set $x_N - x_M \neq 0$, if $sign(x_N - x_m) = sign(x_L)$, the M is the in point and the N is the out one, otherwise the N is the in point and the M is the out one.

3.3. Optimization image synthesis

The last step of volume rendering is image synthesis; there are two kinds of image synthesis methods: former backward method and after forward method. We know that former backward method has more advantage than after forward method: using the former backward method for image synthesis the opacity value O must be increases slowly. When it closes to 1, the voxel behind the light will not have any contribution to pixel image, so they can finish calculation. Because the former backward synthesis can remove many useless calculations and improve the speed, so this paper adopts former backward method to image synthesis.

4. 3D reconstruction and visualization of concrete

This paper's developing environment is as follows: CPU is Intel (R) Core (TM) 2 Duo, memory is 2.00 G, hard disk video is 250G and discrete graphics; System software is Windows 7; realized with VTK and VC6.0 mixing programming. System realized c++ programming with using core algorithm, visualization with VTK, a graphical interface design with powerful MFC and integration system with VC6.0.

4.1. VTK visualization tool

VTK [6] (The visualization Toolkits) is a visualization and image processing toolbox which has object-oriented method design and powerful function. It is developed on the basis of OpenGL, not only does it based on c++ class library, but also support the various scripting language like TCL, Java, Python and *etc.* While it also support many kinds of operating system such as Unix, Windows. VTK can handle many data format, such as bitmap, image, body metadata, *etc.* VTK using object-oriented ideas shielding up many details visualization develop process, at the same time, capsulation some regular used algorithm, such as frequently used visual light projection algorithm, MC algorithm, *etc.*, that convenient software developers. Meanwhile, VTK is open source code; everyone can access to and use it for free, and can also develop your needs class library based on its original class library.

4.2. The results of 3D reconstruction concrete

We select the four groups of test data to experiment: Static load respectivelyσ=0.00MPa, 36.08MPa, σ=32.22MPa, σ=12.7MPa. Figure 6 shows the effect of image that 3D reconstruction concrete section by improved accelerating algorithm. The rendering time chart data as Table 1.

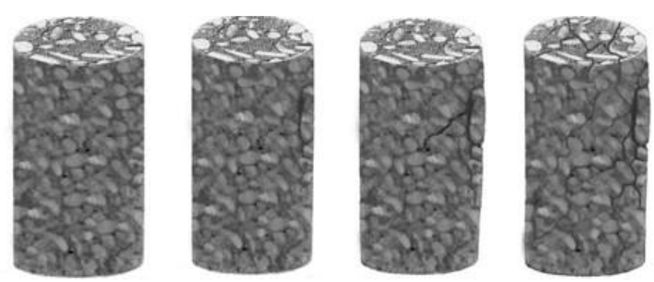


Figure 6. Three-dimension Reconstruction of concrete CT on speedup arithmetic

Figure 6 shows the reconstruction images of concrete by modified ray-casting algorithm is better than the reconstruction results from literature [3]. We can see true internal construction of concrete, such as the aggregate, the caves, *etc.* Especially various stress stages initiation meso-crack can also clearly distinguish.

Table 1. Contrast of arithmetic time

Rendering Time/s \ Test data	The traditional algorithm		Accelerate algorithm	
	Pretreatment	Rendering	Pretreatment	Rendering
σ=0 MPa	15.5	15.6	16.3	2.6
σ=36.08 MPa	15.5	15.8	16.3	2.7
σ=32.22 MPa	15.7	15.9	16.5	2.8
σ=12.7 MPa	16.3	16.1	17.1	3.0

In Table 1, because of many works are complete in preprocessing such as accelerated algorithm for convex hull, casting polygon scan conversion, that accelerate algorithm in pretreatment stage spends more time than traditional algorithm. But it brought great benefits is shortened rendering time. Modified ray-casting algorithm has a significantly accelerating effect for speed of rendering of traditional ray-casting algorithm.

4.3. Visual system of concrete CT image

The paper developed a set of visual CT image system for concrete. DICOM CT image visual system of concrete is divided into file input module, image preprocessing module, 3D rendering module, interactive display module and 3D display module，as figure 7 show. File input module mainly completes single and batch image’s reading and displaying of CT images to DICOM format of concrete. Image preprocessing module use a median filter to operation the image, and it provide a dynamic window wide, window a regulation and mirror function. The 3D rendering module is to reconstruction the 3D image of concrete by modified ray-casting algorithm. Interactive display module provides the function that the 3D reconstruction body can be rotation and zoom after the reconstruction. 3D display module provides sagittal and coronal section display function. The Figure 8 is the effect of operation.

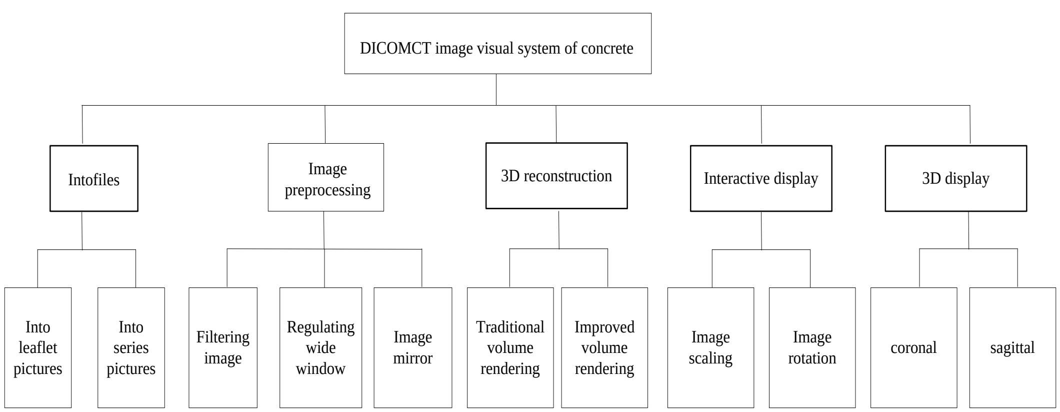


Figure 7. Visualization system structure figure of concrete

Figure 8 (a). figure circumgyrated

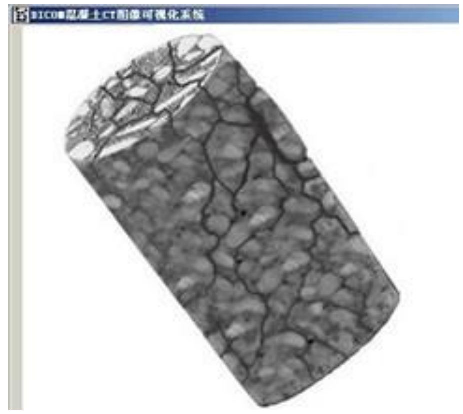


Figure 8 (b).figure enlarged

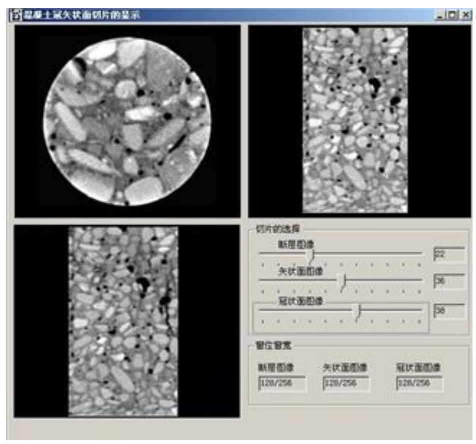


Figure 8 (c).Slice up in shown

Figure 8. Effect of visualization system

5. Conclusions

In order to study the mechanical characteristics of concrete that is heterogeneity of composite materials accurately, many researchers have already established the mathematical model of random aggregate concrete for researching meso-fracture mechanism of concrete. Although this model of concrete structure in aggregate with shape and distribution are more and more close, the concrete aggregate shape and distribution after all is virtual, and has very big difference with real concrete specimens.

So, more and more researchers hope to through more accurate method to express real meso-structure of concrete. This paper using modified ray-casting algorithm, the results showed that the reconstruction results is more precise than before. It provides an effective supplementary methods for establishment of accurate finite element numerical meso-structure model of concrete.

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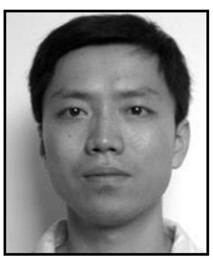

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