Using laser scanning technology to 3D Imaging and study on volume measurement

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Abstract

Based on the necessary of large volume fast measurement of material stack, this article introduced the principle of laser scanning technology in achieving 3D imaging and volume measurement, and the method of establishing 3D surface model with coordinate conversion and image processing effectively, in order to improve the accuracy of volume measurement in material stack. Experimental result shows good characteristic of speediness, accuracy and short periodic.

Keywords: coordinate conversion, image processing, surface model, volume measurement

1 Introduction

Because of its high measuring speed, moderate accuracy, low cost and robustness in the industrialfield, 3D laser scanning has been widely used in a variety of applications [1]. The laser scanning method allows the non-destructive generation of 3D point clouds representing the spatial structures directly. Applied in forests, fruit tree crops and vineyards parameters like leaf area, stem height, stem volume and biomass were also deduced [2]. These simple 2D representations might provide sufficient accuracy to measure seedlings of cereals or vegetables and rosette plants [3]. Because of the feasibility of scanning from multiple positions around the object, this technique provides a new scale of resolution making possible a m ore specific analysis of the complex morphological 3D structure of older cereal plants, as well as for specific organs [4]. A further contribution to the development of three-dimensional acquisition systems is given by the remarkable possibilities offered by today's three-dimensional visualization and 3D modelling ： the widespread that 3D is taking in areas of daily life with the progressive development and diffusion of products such as virtual reality or augmented reality means that the stimulus in the search for new methods of acquiring competitive, low-cost and thus increasingly accessible to many is truly remarkable[5].

Structured light 3D laser scanning has been studied over the past several decades [6]. It offers a number of advantages, including noncontact measurement, fast measuring speed, a simple optical arrangement, moderate accuracy, low cost and easy extraction of the light stripe image information [7-9]. Range Sensors have been used for 3D object acquisition, the efficiency and accuracy of the technique has been demonstrated using indoor objects [10-13]. Traditionally, a large dynamic range of scene radiances is acquired by combining several varying exposures of the scene [14, 15].

In real life, it's very important to carry out volume measurement of the large material stack, including coal, grain, fertilizer and building materials. For example, coal storage and daily consumption of coal yard is an important metrics of thermal power plants, coal mines and other units. Most significant part goes down to measure the size of irregular coal heap, while it becomes a vital factor that affects the economics of power plants and management level on measuring quickly, accurately and effectively.

Speaking of coal, the traditional methods of measurement was using bulldozers to shape the coal, and heaping up as trapezoid artificially before the manual measurement, or calculated through the section plane of the coal pile. It required flat bottom surface, lots of manpower and material resources. This method remained a low measuring accuracy (about >5% error) and efficiency. The workload was about three to four days.

The same problem was found in food and other ecological research. As we can see, measurement of irregular shape grain size would directly influence the management of food storage. The volume determination of crown would increase the fitting accuracy of component biomass model and estimate. It is also an important part in the ecological environment.

As far as all above, it is very market valuable to design a program to determining irregular volume precisely and rapidly. Combining with 3D laser scanning technology, and short time, dense and high-precise laser scanning, an irregular solid surface under Puslar apparatus and Starsurvey3d instrument is used to generates the respective point cloud(3D coordinates).Then it will be image processed, and simulate the real dimensions of the whole solid surface in a 3D surface model. Finally, its volume would be calculated by a particular program. The advantage of whole operation is automatic, fast, accurate, high-precision, economic-saving, and low testing period and will be very beneficial to scientific management in factory. This measurement can help enterprise arrange the quantity of vehicles, as long as the accurate data of storage capacity in order to make the regulation more scientific.

2 Relative work

With the development of measurement technology, foreign measurements mainly include binocular photogrammetry, 2D laser scanners measurements, and 3D laser scanners measurements.

Binocular Stereo Vision is an important form of machine vision. Based on the principle of parallax, using the imaging equipment to get two image of detected objects from different locations. It obtains the 3D geometric information by calculating the position deviation between the corresponding points of the image. However, in terms of large scale stock yard, it is not good using binocular stereo vision for volume measuring because of its large area .Besides, it will causes the poor robustness problem by using self-calibration of camera.

The 2D laser scanning technology is using 2D laser scanners to determine the section of two-dimensional coordinates. Displacement sensors and angular sensors are used to achieve the orientation of the 3rd coordinate. Combining with two data sets, it shows a large number of discrete coordinate points in the entire field. So we can calculate the volume of coal pile with the TIN triangulation algorithms. In other words, firstly coal pile surface point in the projection surface can get a large number of discrete point coordinates of the bottom surface, that is, three dimensional coordinate system turned into a two dimensional coordinate system. Secondly, the two-dimensional coordinates points of bottom turn into triangular meshes. The last, we connect the points of surface and the points of bottom longitudinal, hence we will attain a lot of straight triangular prism. All three prisms accumulated can be derived the volume value of material. All three prisms are disjoint and adjacent to each other, so the accumulated value can be expressed as below:

$$V = V_1 + V_2 + V_3 + ... + V_i + ... + V_n = \sum_{1=0}^{n} V_i \quad (1)$$

In the Equation, the most important step is calculating the volume of the triangular prisms. Every triangular prism can be divided into a regular triangular prism and a tetrahedron by using an accurate algorithm, that is to say, the volume of target is the summation of the regular triangular prism and the tetrahedron, making it easy to calculate the volume. However, it is hard to calculate the volume of irregular tetrahedral. The Euler equations, matrix and vector was used as well as costing great workload and very inconvenient.

3 The measurement of B-spline

In the process of laser scanning, it is difficult to obtain all data in the same point. The measuring instrument is moved, known as moving stations. After moving stations, the measured data is different because of the changing location. At this time, all of the data should be integrated into the same coordinate system.

3.1 OBTAINING THE COORDINATE OF CONTROL POINT

We use two coordinate systems before moving as an example. In Figure 1, O_1 is used as a measuring instrument before moving in coordinate systems, and O_2 as a measuring instrument after. The origin vector of O_1 and O_2 is (a, b, c).

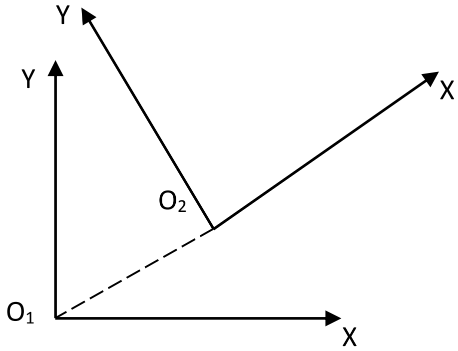

FIGURE 1 Moving station before and after

In each coordinate system, there is a positive direction in the x axis. Direction angle anticlockwise starts from the north direction, and ends in the angle of direction. These angles in two coordinate systems can be calculated through all direction angles. In Figure 2, the Φ is the angle between two coordinate systems.

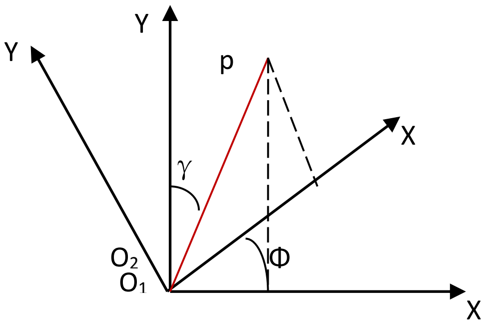

FIGURE 2 Coordinates conversion map

The angle of γ can be calculated by the x-axis orientation in O_1 coordinate system, or by the x-axis angle in O_2 coordinate system with the angle in the direction of the P point. Setting the coordinate of P as (Px1, Py1, Pz1) in the coordinate system. Then we can obtain:

$$Px1 = OP \cdot \sin\gamma , \quad (2)$$

$$Py1 = OP \cdot \cos\gamma . \quad (3)$$

Setting the coordinate of P is (Px2, Py2, Pz2). Then we can obtain:

$$Px2 = OP \cdot \cos(\frac{\pi}{2} - \lambda - \phi) , \quad (4)$$

$$Py2 = OP \cdot \sin(\frac{\pi}{2} - \lambda - \phi) . \quad (5)$$

Thus, the conversion of P is derived in two coordinate system:

$$Px2 = Px1 \cdot \frac{\sin(\gamma+\phi)}{\sin\gamma} + a\,, \tag{6}$$

$$Py2 = Py1 \cdot \frac{\cos(\gamma+\phi)}{\cos\gamma} + b\,, \tag{7}$$

$$Pz2 = Pz1 + c\,. \tag{8}$$

3.2 THE MEASUREMENT OF B-SPLINE CURVE

The Equation of B-spline curve is defined as:

$$P(t) = \sum_{i=0}^{n} P_i N_{i,k}(t), \quad (t_{\min} \le t \le t_{\max}\,,\ 2 \le k \le n+1)\,. \tag{9}$$

In this Equation, P_i (i=0,1,…,n) control (n+1) vertex in polygon, and $N_{i,k}(t)$ (i=0,1,…n) is called B-spline basis function of k-order(k-1 th).The range of parameters t depends on other parameter selection of B-spline. K is a first-order parameters and order parameters can be assigned to any integer from 2 to n+1.In fact, it can also be set to 1, but it happens to be the control point itself. Local control of B-spline can be expressed by the mixture functions which are defined in the range of t.

The mixture of b-spline basis function is defined by the recursive of deBoor - Cox:

$$N_{i,1}(t) = \begin{cases} 1\,, & t_i < t < t_{i+1} \\ 0\,, & \text{Otherwise} \end{cases}\,, \tag{10}$$

$$N_{i,k}(t) = \frac{t - t_i}{t_{i+k-1} - t_i} N_{i,k-1}(t) + \frac{t_{i+k} - t}{t_{i+k} - t_{i+1}} N_{i+1,k-1}(t)\,, \tag{11}$$

B-splines can be designed as a curve by changing the number of control points without number of polynomial. You can also add or modify the number of control points to control the shape of the curve.

B-spline surface is made up of two B-spline curve in the direction of intersecting grid with the Equation:

$$P(u,v) = \sum_{k_u=0}^{n_u} \sum_{k_v=0}^{n_v} P_{k_u k_v} \cdot B_{k_u k_v}(u) \cdot B_{k_u k_v}(v)\,. \tag{12}$$

In the formula, the vector $P_{k_u k_v}$ specifies the location of the control point $(n_u+1)\cdot(n_v+1)$. B-spline surface has the same property compared with B-spline curves. The value of the selected parameter d_u and d_v determine the times of polynomial number d_u-1 and d_v-1. Choosing the knot vector for each surface parameters u and v, it was used to determine the range of mixed function parameters.

4 Comparative analyses of the traditional method and B-spline curves

In this work, the polar axis is converted to space rectangular coordinate system through obtaining azimuth and distance between target point and the station by laser scanning. The reference frame is used to find the basic laws of moving station. Then using B-spline surfaces which have higher degree of fitting to simulate practical model of coal pile. Finally, using the differential principle to get volume of the coal. There will be some errors, but the results were amended so that error is acceptable.

TABLE 1 Comparative analysis of the traditional method and B-spline curves

	Advantages	**Disadvantages**
Binocular Photogrammetry	High precision, Fast operation, Device structure is simple	Difficult to measure large objects, Poor robustness
Two-dimensional laser scanning	Applies only to regular objects	Complex calculation to irregular volume
B-spline curves	Economic and rapidly, High precision, High surface fitting	B-spline is more complex than Bezier splines, Devices require high performance

By comparison, we can see that B-spline curves used for volume measurement has a higher fitting degree. Besides, it can also measure large or irregularly objects. In conclusion, application of B-spline curve is more extensive.

5 Experiment simulation

Though the experiment simulation, we will better to understand how the B-spline curves work .

5.1 B-SPLINE SURFACE MODELING EXPERIMENT

There are three coordinates for each control point, X, Y, Z, it builds a class based on the coordinates:

```
class Point3D
{
public:
   double x, y, z;
public:
   Point3D(double thisx, double thisy, double thisz)
   {
      x=thisx;   y=thisy;
      z=thisz;
   }
};
```

In order to facilitate the description of the experimental process, we can input the experimental data to test the results, and the control point is stored as a three dimensional array.

TABLE 2 Control points

Points			
(0,1,80)	(0,20,60)	(0,40,40)	(0,60,20)
(0.87,0.5,80)	(17.4,10,55)	(34.8,20,35)	(52.2,30,15)
(0.87,-0.5,75)	(17.4,-10,60)	(34.8,-20,40)	(52.2,-30,20)
(0,-1,80)	(0,-20,55)	(0,-40,35)	(0,-60,15)
(-0.87,-0.5,75)	(-17.4,-10,60)	(-34.8,-20,-40)	(-52.2,-30,20)
(-0.87,-0.5,75)	(-17.4,10,55)	(-34.8,20,35)	(-52.2,-30,15)
(0,1,80)	(0,20,60)	(0,40,40)	(0,60,20)

The total control points are:

$$(n_u+1)\cdot n_v+1) = (3+1)\cdot 6+1), \qquad n_u = 3,\ n_v = 6.$$

In the platform of OPENGL, the drawings of control points are shown in Figure 3. It mainly lies on four surfaces:

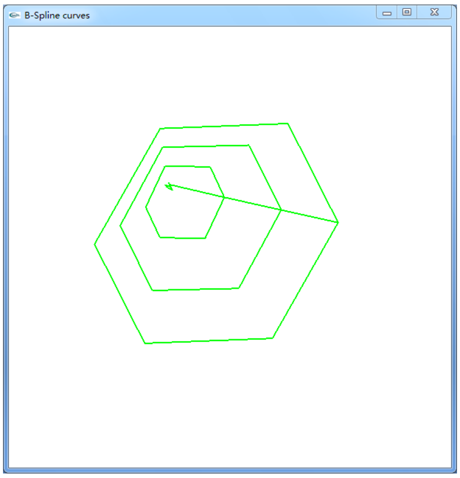

FIGURE 3 Control point of the drawing

Setting $d_u=d_v=3$, the number of vector nodes in u direction is $n_u+d_u+1=7$ and the number of vector nodes in v direction is $n_v+d_v+1=10$. Control points have formed a closed curve. Set the knot vector for uniform B-spline curve, and nodes at both ends are repeat, and in the middle the node spacing is uniform.

By programming the B-spline surface, the simulation results are shown in Figure 4:

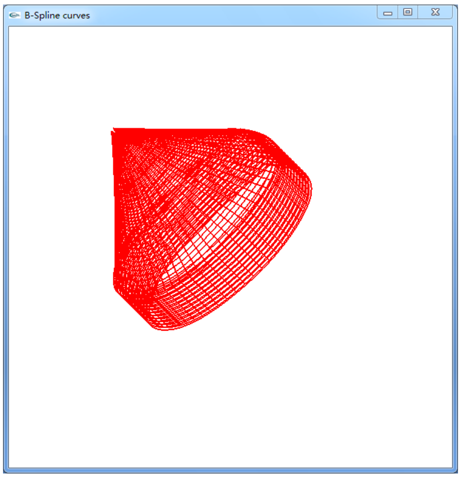

FIGURE 4 Control point on the simulate surfaces

In order to research deeply, we rotate the image, that shown in Figure 3 and Figure 4 above.

5.2 CALCULATION THEORY AND EXPERIMENT

Through the B-spline surfaces, we can attain the points on the surface. We'll also regard the coal volumes as the sum of tiny elongated cube by using the ideas of calculus.

The coordinates of each point on the surface was calculated in the programming process is as follows:

```
Point3D calPuv(double u, double v)
{
   Point3D puv  = Point3D(0,0,0);
   for (int ku = 0; ku <= nu+1; ku++)
   {
      for (int kv = 0; kv <= nv+1; kv++)
      {
         puv.x += ctrlPts[ku][kv].x
                 * Bfunction(ku, du, u, uarray)
                 * Bfunction(kv, dv, v, varray);
         puv.y += ctrlPts[ku][kv].y
                 * Bfunction(ku, du, u, uarray)
                 * Bfunction(kv, dv, v, varray);
         puv.z += ctrlPts[ku][kv].z
                 * Bfunction(ku, du, u, uarray)
                 * Bfunction(kv, dv, v, varray);
      }
   }
   return puv;
}
```

Bfunction () is the function of B-spline curves and surfaces, it uses a recursive formula called the deBoor-Cox to calculate.

Using the experimental data in the previous section, the total volume is 466619.888415.

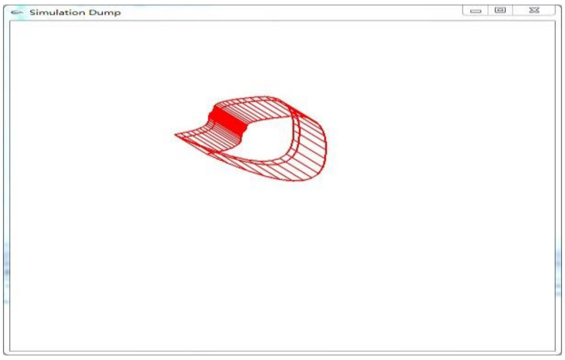

FIGURE 5 The interface of image simulation

6 Conclusions

This paper introduces the working principle of using laser scanning technology to achieve 3D imaging and volume measurement. In order to get a proper fitting surfaces, this paper uses the B-spline method. Compared with the traditional method of calculating, this method is more convenient for them. Meanwhile, using differential method to calculate the volumes, which have higher accuracy in the system.

FIGURE 6 3D laser scanner

This simulation results demonstrate the feasibility of the experiment. Meanwhile, through this experiment, we have concluded that measurement errors come from the location of control points in the system. Therefore, the working direction in the future is mainly to the control point selection, in order to make more realistic shapes of 3D imaging, and then the accuracy of volume measurement will also improve.

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