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Calculation method of surface shape feature of rice seed based on point cloud

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ABSTRACT

Surface shape feature is a very important index of seed classification. A method to calculate the three dimensional characteristics of the rice seed based on its surface point cloud was investigated. First of all, a laser scanner was used to acquire the three dimensional point cloud (TDPC) of a rice seed, then based on the principal component analysis (PCA) the TDPC were translated and rotated to normalize coordinate system. The length, width and thickness of rice seed, and furthermore its elongation, flakiness, shape factor and sphericity could be calculated by the oriented bounding box (OBB). We can generate mesh surface of the rice seed surface point cloud by the greedy triangulation algorithm, then calculate the surface area of the rice seed. On the basis of the slice method, an improved method based on rice seed TDPC was proposed to calculate the volume of rice seed. Compare the calculated length, width thickness and volume of different rice seeds with manual measurement. It is found that the average error is less than 1.5%. A ball whose radius is known instead of a rice seed to be used to verify the validity of the surface area by comparing the calculated value with their theoretical value, the mean error is 0.55%. The results showed the calculation method could acquire the surface shape feature of rice seed based on the TDPC and it is valid enough for application, this method is applicable for measurement of other irregular object as well.

1. Introduction

Rice is the most important cereal crop in China, and its planting area accounts for 30% of the total grain crop planting area in China. The purity of rice seeds is a key factor affecting the rice yield. The lower the purity of rice seeds, the lower the rice yield. Since rice seeds are often mixed with other varieties, coarse cereals and seed parents, finding a fast, lossless and accurate method of identifying rice seed purity is of great importance.

The surface shape feature of seeds is a very important index of classifying and recognizing seeds, and the morphological identification of seeds is a key method of recognizing seeds in biology (Kurtulmu and ünal, 2015; Szczypiński et al., 2015; Mebatsion et al., 2012, 2013). In traditional seed identifying methods, manual identification is conducted according to the differences in surface morphology, which has tedious operations with large identification errors, and only coarse identification can be made. Currently, studies on rice seed purity detection based on seed surface morphology features mainly use computer vision technology to extract the shape, color, texture and moment features of seeds for seed classification and recognition. For example, (Wang et al., 2010) extracted 13 geometrical features of corn seeds, including area, circumference, long axis, short axis, etc., and 12 color features, including the mean value of each component of RGB, HSI color spaces, and applied neural networks (NN) for the classification of 4 species of corn seeds, with recognition rate larger than 97%. Zhu et al. (2012) used hyper spectral images of corn seeds to extract the entropy information of specified bands, and applied partial least squares projection algorithm to extract 65 optimal band features for corn seed classification and recognition, with recognition rate up to 99.19%. Zhao and Wang (2011) extracted the two-dimensional features of weed seeds. Nine invariant moments, including the ratio between seed perimeter and hilum perimeter, the ratio between seed area and hilum area, etc., as well as 7 invariant moments based on Hu's moment were extracted. Weed seed classification was performed based on these features. Meizhi (2010) processed rice seed images and extracted texture features including entropy, energy, inertia moment, local stationarity, etc., and EQP texture feature distribution. Support vector machine was used to classify rice seeds. Shouche et al. (2001) extracted 6 shape features of wheat seeds, including area, perimeter, long axis, etc., and moment features, including original moment, invariant moment, central moment, normalized central

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moments, etc. The difference of shape features and moment features in representing wheat species was analyzed. Zapotoczny (2011) extracted 21 texture features in 7 color components for representing wheat seeds, and used them to classify 11 species of spring and winter wheat, achieving 100% classification accuracy. Choudhary et al. (2008) obtained 51 shape feature sets, 93 color feature sets, 56 texture feature sets and 135 wavelet feature sets by image processing. Then individual feature sets and combined feature sets were used for classification, and the recognition accuracy of feature set combination was 99.4%, 99.3%, 98.6% and 98.5% for wheat, rye, barley, and oats, respectively.

The aforementioned methods are simple and easy to implement, and the detection and recognition of different species can be achieved under certain conditions. However, the two-dimensional image features are the simplification of three-dimensional images of seeds, and the three-dimensional features of seeds are not considered, which limits the detection accuracy. Therefore, in both theory and real applications, the features of seeds should be extended to include the third dimension. In this study, we focus on rice seed purity identification problem, and propose to use the laser point clouds to extract the shape features of rice seed surfaces, then discuss the calculation method of the three dimensional parameters of rice seeds, which provides reliable three-dimensional data for later rice variety identification and other industrial application.

2. Material and methods

2.1. Experimental samples

The test materials are Yujing No. 6 rice seeds (Fig. 1). The seeds are sown in May, with

- Growth period: 150 days;
- Plant height: around 100 cm;
- Main stem leaves: 16 or 17;
- Spike length: 15–17 cm;
- Average grain number per spike: 110–130;
- Seed setting rate: 90%.

The grains have an oval shape, weigh 25–26 g per thousand grains, and have highest yield per unit area over 800 kg.

2.2. Three-dimensional laser scanning system

The adopted three-dimensional laser scanning system is composed of the control module, the driver module and the measurement module. The control module includes a computer, an image acquisition board and a motion controlling board embedded on the computer main board. The driver module includes three axial servo drivers and servo motors. The measurement module includes the measuring head, which contains a CCD camera and a semiconductor laser generator, as shown in Fig. 2. The laser scanning system uses double CCD measurement, with highest scanning precision of ±0.01 mm. After system initialization, the measurement module is driven by the motion controlling board and the image acquisition board to perform the digitization process of rice seed surface shapes. Then, the collected point cloud data are saved in the computer in text format for later analysis and processing.

Fig. 1. Sample pattern.

2.3. Collection of rice seed point clouds

In the process of collecting the point clouds of rice seeds, laser scanner can only collect one side of rice seeds. To obtain the complete information of rice seed surfaces, the data acquisition should generally be conducted from at least 3 viewpoints of rice surfaces. Since the coordinate systems of the point cloud data in different viewpoints are different, the point data of different pieces of rice seed surfaces should be registered to a global coordinate system. In this study, the data are collected from 4 viewpoints of rice seed surfaces, and Geomagic Studio software is used for registration.

First, a square rice seed holder with 8 mark points is designed, with the front and rear azimuth of each plane having one mark point. In measuring process, the rice seed samples are held by the rice seed holder, and are relatively fixed to the seed holder. Scanning is performed at an interval of 90° for the joint body. After obtaining the pieces of point clouds in different viewpoints, the point clouds of the joint body are registered by performing the registration of the mark points in all views according to the invariance of the mark points on the holder and the relative position of views. Finally, the holder in the point clouds of the joint body is removed, resulting in the point clouds of rice seeds. The data processing of Geomagic Studio software is shown in Fig. 3. Fig. 3(a) to (d) show the point cloud data in 4 viewpoints with an interval of 90°. Fig. 3(e) shows the point cloud of the joint body registered using the mark points. Fig. 3(f) shows the collected point cloud of a rice seed.

2.4. Preprocessing of point clouds

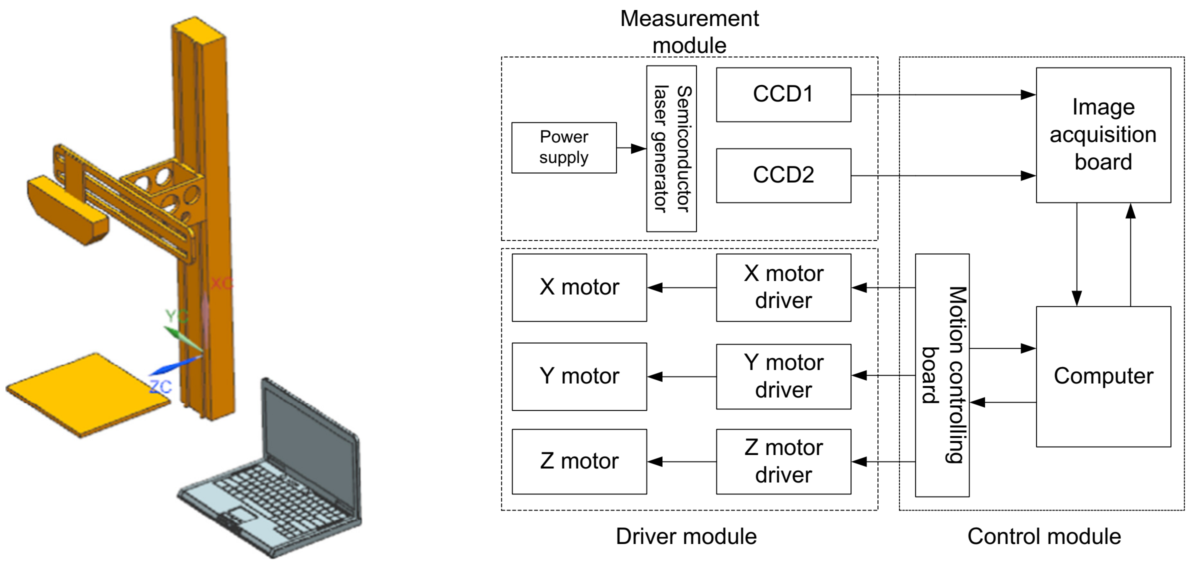
The preprocessing of point clouds includes filtering, smoothing, hole filling, and point cloud simplification. The preprocessed point clouds are the basis for the subsequent calculation of three-dimensional geographic feature values of rice seeds.

2.4.1. Point cloud filtering

Due to the limitation of device accuracy and CCD camera resolution, and vibration in scanning process, the collected point clouds may contain sparse outliers. Using filtering algorithms for outliers can remove noise points in point clouds (Rusu et al., 2008). Based on experimental selection and testing, the number of neighboring points of the queried point in statistics is set as 10, with distance threshold set as 1.

2.4.2. Point cloud smoothing and hole filling

Errors generated in measuring process may cause the point clouds of rice seeds to be unsmooth or contain holes. Therefore, the point clouds should be smoothed and the holes should be filled. Moving least square (MLS) method based smoothing and resampling algorithm is used to smooth the point clouds and fill holes (Kim et al., 2015). Using the noise-removed point cloud as the test samples, the effect of smoothing and hole filling is shown in Fig. 4, where Fig. 4(a) shows the test sample, and Fig. 4(b) shows the point cloud after smoothing and hole filling (with a searching



(a) Line laser scanner (b) System module diagram

Fig. 2. Laser scanning system.

radius of 0.35 mm). It is clear by comparing the two figures that using MLS based smoothing and hole filling algorithm can well fix the small holes in point clouds; meanwhile, the coordinates of the point clouds can be appropriately adjusted while the surface features of rice seeds are retained.

2.4.3. Point cloud simplification

The point clouds of rice seeds measured by laser scanning are very dense, and the data are highly redundant. Therefore, after point cloud smoothing and hole filling, the point clouds should be simplified. Using voxel based grid method to down sample the point clouds can reduce the number of points (Wei, 2007). The bounding box of the point cloud is divided into small cubic lattices with volume 1 mm^3 along three directions parallel to the coordinate axes. In each cube, all the points within the cube are replaced by their centroid. The number of points is then reduced from 16,915 to 2740, and the structural information of rice seeds is well preserved, as shown in Fig. 5.

2.5. Length, width and thickness of the grain

An oriented bounding box (OBB) is a rectangular bounding box in any direction of the three-dimensional space. It has arbitrary direction, and can surround the target object as much as possible according to the shape of the object.

The length, width, and thickness are the main features describing the grain shape. By establishing the OBB of grain sample models, the length, width and height of the OBB can represent the length, width, and thickness of grain samples.

(1) Translation transformation. Translate the centroid of point cloud model to the origin of the new coordinate system. First, the centroid of the point cloud model, c, is found:

$$c = \left(\sum_{i=1}^{N} p_i\right)/N \tag{1}$$

where p_i is the *i*-th point of point cloud P, and *N* is the number of points in the point cloud.

The origin of the coordinate system of the point cloud model is moved to c, forming the new point cloud set $P_1 = \{p|p = p - c, p \in P\}$;

(2) Rotation transformation. A rotation matrix is constructed using principle component analysis (PCA) method Jiang et al., 2012, and the point cloud is transformed into a new coordinate system. The covariance matrix is constructed according to the point set of the given model, and the eigenvalues and eigenvectors are calculated. Since the three eigenvectors are mutually orthogonal, a new coordinate system can be defined, and the model can be transformed into the normalized coordinate system.

Let $P_1 = \{p_i\} \in S^3$, $i = 1, 2, \ldots, N$ be the point set of the rice seed model, and $c = E\{P_1\}$ be the centroid of the point cloud. Then, the covariance matrix of point cloud model, $\boldsymbol{C_p}$, is:

$$C_p = E(\{(p-c)(p-c)^T\} = \frac{1}{N}\sum_{i=1}^{N}(p_i - c)(p_i - c)^T \tag{2}$$

C_p is a symmetric matrix, and has 3 eigenvalues, λ_1, λ_2 and λ_3, satisfying $\lambda_1 > \lambda_2 > \lambda_3$. Meanwhile, there are three corresponding unit eigenvectors, e_1, e_2 and e_3, satisfying:

$$C_p e_i = \lambda_i e_i \tag{3}$$

Then, rotation matrix $\boldsymbol{R} = \{e_1, e_2, e_3\}^T$ is used to transform point cloud model P_1 into a new coordinate system, i.e., PCA coordinate system;

(3) Calculating OBB. 6 points with the minimum and maximum X, Y, Z coordinates are located on the point cloud. Let their coordinates be x_{max}, x_{min}, y_{max}, y_{min}, z_{max} and z_{min}, then

$$l = x_{\max} - x_{\min} \tag{4}$$

$$w = y_{\max} - y_{\min} \tag{5}$$

$$h = z_{\max} - z_{\min} \tag{6}$$

where l, w and h are the length, width and thickness of a grain, respectively.

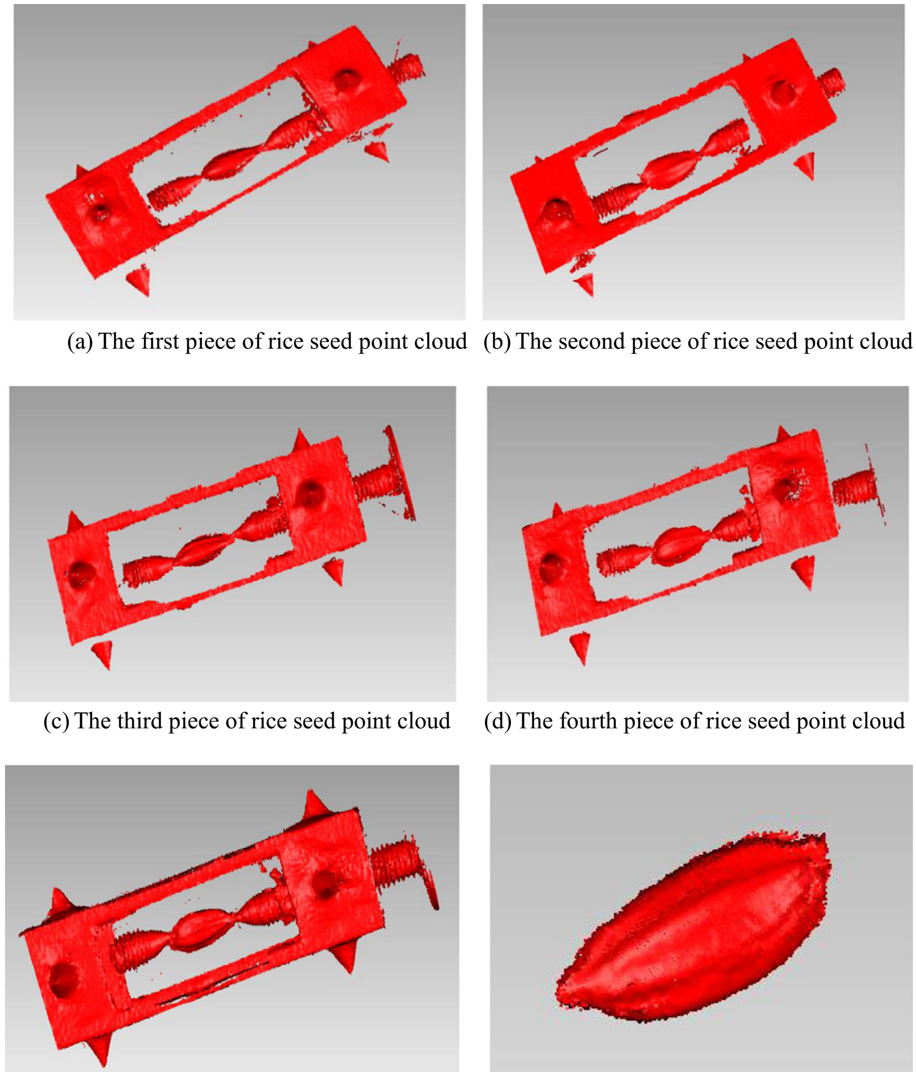
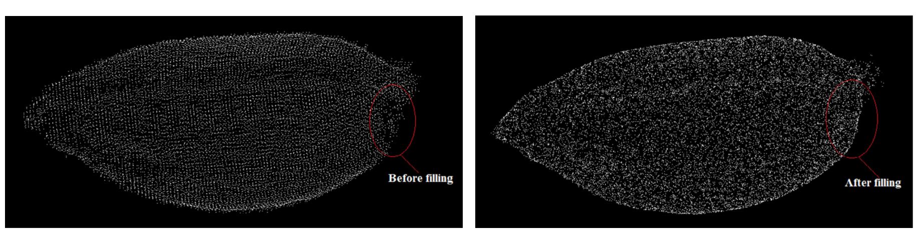

(a) The first piece of rice seed point cloud (b) The second piece of rice seed point cloud
(c) The third piece of rice seed point cloud (d) The fourth piece of rice seed point cloud
(e) The joint body point cloud (f) Rice seed point cloud

Fig. 3. The acquisition of rice seed surface point cloud.



(a) Point cloud before filling (b) Point cloud after filling

Fig. 4. Smoothing and fixing of points.

2.6. Needle degree, flatness, shape factor and sphericity of grains

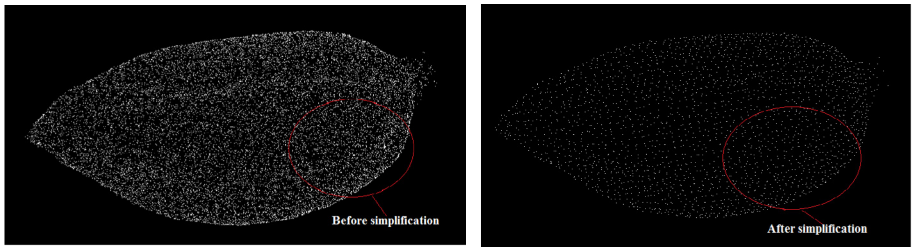
The surface morphology is approximately an ellipsoid. Therefore, we introduce needle degree (Θ), flatness (Φ), shape factor (F), and sphericity (Ψ) as the quantification indices of rice seed shape (Zhang et al., 2016; Pang et al., 2007), in order to assess the outline shape of rice seeds. The equations are as follows.

$$\Theta = l/w \tag{7}$$

$$\Phi = h/w \tag{8}$$

$$F = \frac{p}{q} = \frac{hl}{w^2} \tag{9}$$

$$\psi = \left(\frac{wh}{l^2}\right)^{1/3} \tag{10}$$



(a) Point cloud before simplification (b) Point cloud after simplification

Fig. 5. simplification of points.

2.7. Grain volume

On the basis of the slice method (Pang et al., 2007), an improved method based on rice seed point clouds is proposed, with the detailed steps as follows.

(1) Point cloud model cutting. After rice seed point cloud translation and rotation, the point cloud is cut along x direction with equal intervals. The cutting section which has the shortest distance to each point of the point cloud is found, and the projection of each point on this cutting section results in n slices of projected point cloud model, denoted as $P(x_i)$,1,2, ..., n. Fig. 6(a) shows the projection of rice seed point cloud model on the section of *yoz* principal plane.
(2) Contour point extraction of section projection point cloud. Alpha shape algorithm (Chen, 2015) is used to establish the concave package model of the projected point cloud, and the contour points of each point cloud projection section are extracted. Fig. 6(b) and (c) show the concave package and convex package contour points of the point cloud on the projection section of *yoz* plane.
(3) Calculating sectional area. Assume any concave point cloud contains points A, B, C, D, E, F and G, as shown in Fig. 7. Then, the sectional area is composed of the vector areas of the triangles formed by vertex P and A to G. Assume the coordinate order of the point cloud is A to G, and counter clockwise is the positive direction. Then, the areas of PAB, PBC, and PCD are negative, while the areas of PDE, PEF, PFG, and PGA are positive. The sectional area is the absolute value of the sum of the area of each triangle.

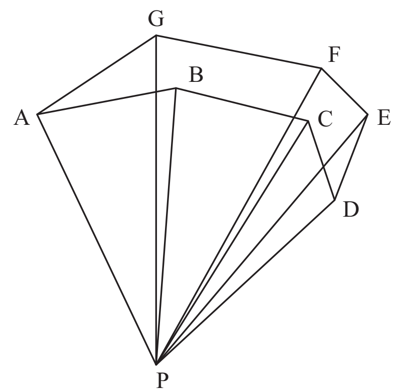


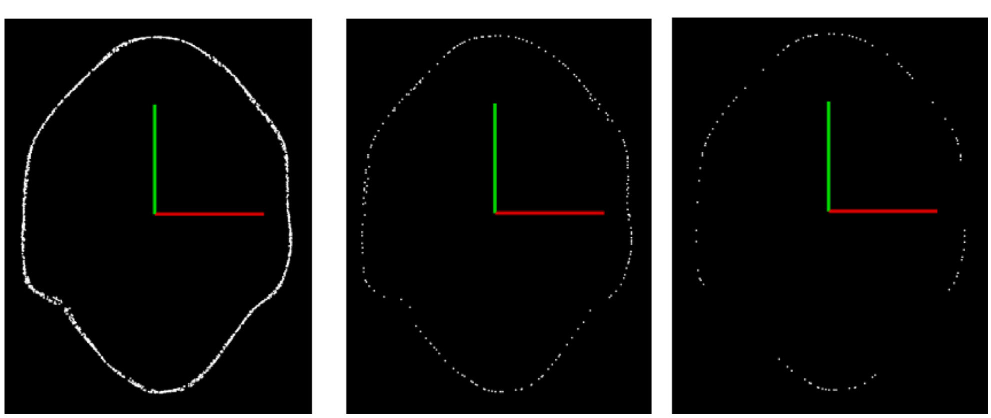
Fig. 7. Example of the concave point set.

(4) Calculating the volume of the point cloud model. The projected sectional areas on cutting planes are $S_0, S_1, \ldots, S_n$. When n is big enough, the volume of the model is approximated as follow.

$$V \approx \frac{x_{\max} - x_{\min}}{n} \sum_{i=0}^{n-1} \frac{S_i + S_{i+1}}{2} \quad (11)$$

Where the volume of the i-th section ($i = 0, 1, \ldots, n-1$) is

$$V_i \approx \frac{x_{\max} - x_{\min}}{n} \frac{S_i + S_{i+1}}{2} \quad (12)$$



(a) Section point cloud (b) Contour points of concave point cloud (c) Contour points of convex point cloud

Fig. 6. Cross section point cloud of Spindle surface.

Let the volume of the n-th cutting be V_n. If the absolute difference between V_n and the volume of the previous cutting, V_{n-1}, is less than a predefined threshold, it is considered that the calculation accuracy has been reached, and V_n is the final result; otherwise, the next cutting is performed for the model.

2.8. Surface area of grain

Surface area is one of the most important shape features of an object. By using greedy projection triangulation algorithm, the triangular mesh model of the point clouds of rice seed samples is established (Marton et al., 2009). The areas of all triangle surfaces are calculated and the sum of them is used to approximate the surface area of the rice seed.

(1) Triangulation of point cloud model. Greedy projection triangulation algorithm is used to triangulate the point cloud model, as shown in Fig. 8.
(2) Calculating the surface area of the triangular model. Assume the triangular model is composed of triangular surfaces $T = \{T_1, T_2, \ldots, T_n\}$, where T_i is the i-th triangular surface of the model with vertices A_i, B_i and C_i. The edge lengths of the triangle a_i, b_i and c_i are computed using Euclidean distance formula. According to Helen formula, the area of the triangular surface is

$$l = \frac{a_i + b_i + c_i}{2} \tag{13}$$

$$S_{A_iB_iC_i} = \sqrt{l(l - a_i)(l - b_i)(l - c_i)} \tag{14}$$

Therefore

$$S = \sum_{i=1}^{n} S_{A_iB_iC_i} \tag{15}$$

where S is the surface area of the rice seed.

2.9. The measure method of grain actual volume

The volumetric compression method (Zue, 1994) is measure the change of pressure before and after loading the material when used to measure the piston in the container to a certain volume and then figure out the volume of the material according to Boyle's law. The working principle is shown in Fig. 9.

A certain mass of gas, when the temperature is constant, the product of pressure and volume is equal to the constant value. Assuming that the volume between A and B is V_0 and the volume below B is V. When there is no material in the container to move the plunger's piston A to B. there is

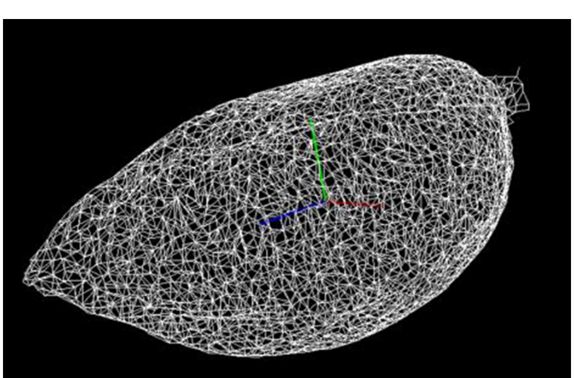
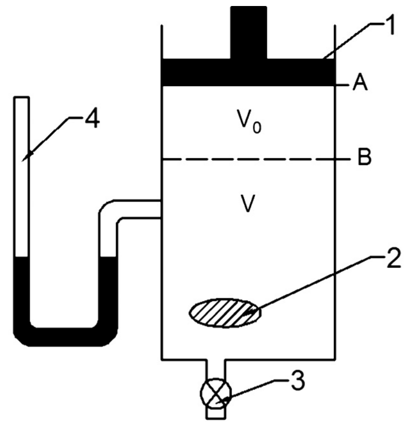


Fig. 8. The triangular mesh.



1. Plunger; 2. Grain; 3. Valve; 4. Piezometer

Fig. 9. The volumetric compression method.

$$(V + V_0)P_a = V(p_a + \Delta P_1) \tag{16}$$

To put the grain in a container and repeat the above operation, according to Boyle's formula:

$$(V + V_0 - V_s)P_a = (V - V_s)(p_a + \Delta P_2) \tag{17}$$

To solve the get:

$$V_s = V_0\left(\frac{p_a}{\Delta P_1} - \frac{p_a}{\Delta P_2}\right) \tag{18}$$

In the formula: V_s is grain volume (mm^3) ;V is the container volume (mm^3) ;V_0 is plunger fixed compression volume (mm^3) ; p_a is absolute atmosphere; ΔP_1 is the pressure gauge reading before load the grain; ΔP_2 is the pressure gauge reading after load the grain.

3. Results and discussion

3.1. Accuracy analysis of feature calculation

The time-consuming of collection and preprocessing of rice seed point clouds is about two hours if you can operate machine and software skillfully. A seed of Yujing No. 6 rice is randomly selected, and arbitrarily placed for three times. Its feature values are measured and calculated at each time, and the results are shown in Table 1. The error of the calculation results for the 3 times is less than 1%, indicating the algorithm is translation and rotation invariant.

3.2. Verification of the calculation method for surface shape feature

3.2.1. Verification of the calculation method for length, width, thickness and volume

50 seeds of Yujing No. 6 rice are selected as experimental samples. The surface shape feature values of each seed are calculated (Table 2 shows the calculated and measured values of 15 seeds). By comparison of the calculated results and the results manually measured by micrometers and 1.9 methods. It is clear that for grain length, width, thickness and volume the errors between calculated and measured values are relatively small, with maximum errors being 0.09 mm, 0.06 mm, 0.06 mm and 0.58 mm^3, with the standard deviation being 0.02, 0.02, 0.02 and 0.10, with the average error being 0.28%, 1.16%, 1.32% and 1.37% respectively, indicating the effectiveness of the calculation methods.

Table 1
Shape parameters of the test seed.

	1st calculated value	2nd calculated value	3rd calculated value	Average value	Standard deviation
Length (mm)	8.04	8.04	8.05	8.04	0.0047
Width (mm)	3.24	3.23	3.24	3.24	0.0047
Thickness (mm)	2.60	2.61	2.59	2.60	0.0082
Volume (mm^3)	27.67	27.70	27.61	27.66	0.0374
Surface area (mm^2)	55.66	55.69	55.63	55.66	0.0245
Needle degree	2.48	2.49	2.48	2.48	0.0047
Flatness	0.80	0.81	0.80	0.80	0.0047
Shape factor	1.99	2.01	1.99	2.00	0.0094
Sphericity	0.51	0.51	0.51	0.51	0.0000

Table 2
The calculation value of grain appearance is compared with the actual value.

No	Grain length			Grain width			Grain thickness			Grain volume		
	Calculated/mm	Measured/mm	Error/mm	Calculated/mm	Measured/mm	Error/mm	Calculated/mm	Measured/mm	Error/mm	Calculated/mm^3	Measured/mm^3	Error/mm^3
1	8.05	8.06	0.01	3.45	3.48	0.03	2.49	2.50	0.01	28.67	28.98	0.31
2	7.90	7.88	0.02	3.27	3.30	0.03	2.45	2.49	0.04	26.89	27.3	0.41
3	8.06	8.08	0.02	3.46	3.48	0.02	2.39	2.41	0.02	27.86	28.43	0.57
4	7.96	7.93	0.03	3.28	3.31	0.03	2.48	2.50	0.02	27.66	28.00	0.34
5	7.83	7.85	0.02	3.24	3.26	0.02	2.52	2.54	0.02	27.55	27.82	0.27
6	7.91	7.93	0.02	3.44	3.39	0.05	2.47	2.51	0.04	27.86	28.2	0.34
7	8.15	8.14	0.01	3.30	3.24	0.06	2.42	2.48	0.06	28.86	28.64	0.22
8	7.93	8.02	0.09	3.33	3.31	0.02	2.41	2.39	0.02	27.85	27.47	0.38
9	7.87	7.90	0.03	3.27	3.21	0.06	2.49	2.45	0.04	27.32	27.6	0.28
10	8.16	8.16	0.00	3.45	3.49	0.04	2.54	2.55	0.01	27.96	27.64	0.32
11	8.09	8.07	0.02	3.42	3.48	0.06	2.58	2.53	0.05	27.65	28.2	0.55
12	7.90	7.92	0.02	3.49	3.44	0.05	2.43	2.47	0.04	26.97	27.22	0.25
13	8.16	8.13	0.03	3.48	3.43	0.05	2.47	2.49	0.02	28.12	28.52	0.40
14	8.17	8.17	0.00	3.36	3.37	0.01	2.54	2.49	0.05	28.02	27.86	0.16
15	8.02	8.01	0.01	3.44	3.50	0.06	2.42	2.47	0.05	28.00	28.58	0.58
Average	8.01	8.02	0.02	3.38	3.38	0.04	2.47	2.48	0.03	27.82	28.03	0.36
Standard deviation	0.12	0.11	0.02	0.09	0.10	0.02	0.05	0.04	0.02	0.53	0.53	0.10

3.2.2. Verification of the calculation method for surface area

Since the surface morphology of the seed is irregular, the surface area are difficult to measure. To verify the effectiveness of the calculation method of surface area, we use a sphere with a radius of 3.5 mm as a sample, as shown in Fig. 10. The calculated feature values are compared with theoretical values (as shown in Table 3). The errors of surface area is 0.55%, indicating that the surface area calculation methods have relatively high accuracy.

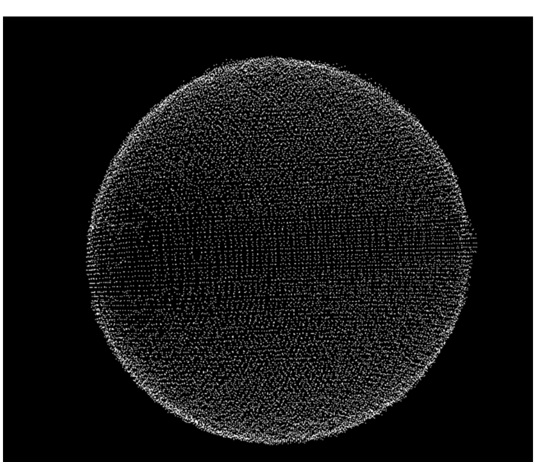


Fig. 10. The Point Cloud of the sample Sphere.

Table 3
Shape parameters of the sample sphere.

Feature value	Calculated value	Theoretical value	Relative error/%
Length (mm)	6.97	7.00	0.43
Width (mm)	6.99	7.00	0.14
Thickness (mm)	6.87	7.00	2.64
Volume (mm^3)	177.12	179.59	1.38
Surface area (mm^2)	153.10	153.94	0.55
Needle degree	1.00	1.00	0.00
Flatness	0.98	1.00	2.00
Shape factor	0.98	1.00	2.00
Sphericity	0.99	1.00	1.00

4. Conclusions

On the basis of the three-dimensional point cloud of rice seeds obtained by laser scanning, the surface shape feature parameters are obtained by point cloud model calculation. The errors are relatively small compared with the actual measured values.

(1) PCA method is used to perform translation and rotation transform for rice seed point cloud model. Then, the OBB of the point cloud model after transformation is calculated. The length, width and height of the OBB are used to represent the length, width and thickness of a rice seed. By comparison of the calculated results and manually measured values, the maximum difference values being 0.09 mm, 0.06 mm and 0.06 mm, the standard deviation being 0.02,

0.02 and 0.02, the mean error being 0.28%, 1.16% and 1.32% respectively. It is found that the average error is less than 1.5%.

(2) The point cloud model is cut in x direction with equal intervals, and concave package algorithm is used to extract the contour of the projected point cloud. An arbitrary point outside the sectional point cloud is introduced, and the sectional area of the point cloud is obtained by calculating the vectorial sum of the contour triangle area. The volume of a single rice seed is the accumulation of the volume of each unit. 15 rice seeds were randomly selected to compare the calculated volume and the theoretical value, with maximum errors being 0.58 mm^3, with the standard deviation being 0.10, with the average error being 1.37%, indicating the effectiveness of the calculation methods.

(3) Greedy projection triangulation algorithm is used to establish the triangular mesh model of the point cloud of rice seeds. Helen formula is used to calculate the surface area of the rice seeds. A sphere with radius 3.5 mm is used as the sample to compare the calculated feature values and the theoretical values, resulting in a relative error of 0.55%, indicating that the surface area calculation methods have relatively high accuracy.

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