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Application of Product Package Design in Safe Cold-Chain Food Logistics

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Abstract

In order to realize non-contact test of commodity over-package, a commodity over-package test system based on grating projection was designed. First obtain the three-dimensional point cloud of an object using one projector and two high-resolution cameras, then extract the bounding box of object point cloud to obtain algorithm, calculate the volume of bounding box and point cloud, and at last, test whether commodity package is over or not according to volume fraction and voidage. Experimental results showed that the system is capable of generating a bounding box effectively based on point cloud shape, and point cloud volume calculation accuracy reaches up to 95%, with time consumption reduced significantly in comparison with the widely used Poisson method.

Keywords*: Package test; Grating projection; Volume measurement; Bounding box*

1. Introduction

The traditional over-package test method is to realize test by manually measuring commodity package's volume using a vernier caliper and a steel ruler and then calculating commodity voidage. Facing more and more frequent tests, demand for rapid and high-accuracy package testing instrument is increasing gradually. Relevant technology research has made certain progress, such as the online testing technique for small package of cigarette, but there is no dedicated over-package testing instrument scheme formed. Hence, developing an over-package testing instrument that could replace traditional testing methods is a problem to be solved. Against problems and shortcomings mentioned above, an improved volume algorithm based on spatially tetrahedral subdivision is proposed in this paper. The basic principle of tetrahedral subdivision method is as follows: divide a spatially geometric model into several tetrahedral units which form the convex hull of target subdivision object according to a certain topological structure, and calculate volume of the model to be tested by calculating volume of all tetrahedral units. In the over-package test system proposed in this paper, first obtain the three-dimensional point cloud of an object employing a grating projection system, obtain a point cloud bounding box according to object point cloud, calculate the volume of point cloud bounding box, then calculate point cloud volume using an improved spatial tetrahedral subdivision method, and at last, put the obtained point cloud into volume fraction and voidage equation to realize commodity package test. Experimental results showed that this test system’s accuracy meets relevant regulations, and it could effectively improve measurement efficiency.

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2. Grating Projection Measurement System

2.1. System Scheme

Design package test system scheme according to relevant over-package testing requirements. Project the pre-modulated grating fringe image onto object surface, gather the fringe image projection information on object surface through a camera, obtain by conversion the three-dimensional data of object surface according to pixel value change of fringes in grating image. Solve phases using the four-step phase shifting method to obtain the three-dimensional point cloud of an object. Register obtained point cloud data into the same coordinate, integrate point cloud data to form the three-dimensional point cloud of an object employing a classical registration method. On this basis, analyze geometrical features of object, conduct three-dimensional Delaunay tetrahedral subdivision, establish tetrahedral grids and calculate point cloud volume. The system analyzes object's overall shape features, intuitively gives measurement results of point cloud of the object to be tested, realizing real-time measurement of object.

During package test, calculate commodity volume fraction and voidage according to obtained volume of bounding box and point cloud. According to relevant regulations, equation for commodity voidage calculation is as shown in Equation (1).

$$X = \frac{\left[V_n - (1+k)V_o\right]}{V_n} \times 100\% \tag{1}$$

X represents package voidage, V_0 represents initial package volume of commodity (*i.e.* volume of the smallest externally tangent cuboid of initial package); V_n is volume of selling package (*i.e.* volume of the smallest externally tangent cuboid of selling package); k is a necessary space factor, and it is taken to be 0.6 in Reference [2].

Definition of volume fraction and its calculation is as shown in Equation (2).

$$\rho = \frac{V_1}{V_2} \times 100\% \tag{2}$$

Where, V_1 is commodity's volume, V_2 is the volume of selling package of commodity.

Specific calculation steps for package voidage and volume fraction of commodity include: calculation of point cloud volume and bounding box volume of selling package, calculation of point cloud volume and bounding box volume of initial package, put obtained volume into Equation (1) and (2) for calculation. Specific flow is given in Figure.2.

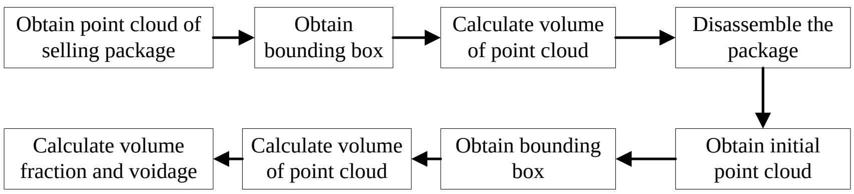


Figure 1. Package Testing Process

The number of packaging layers and package voidage of food and cosmetics required in relevant regulations should be as shown in Table 1.

2.2. Measurement Principle

Grating projection measurement principle is as shown in Figure.2. Project sinusoidal grating onto the surface of an object to be tested, light beams deviate due to object height change, that is, they are modulated by surface shape. Such deviation carries height information of that point; according to classical triangulation measurement principle, height of that point can be obtained based on light beam deviation. The grating projected onto the reference plane in Fig. 3 is a sinusoidal grating, the object to be tested is placed on the reference plane XY (Y-axis is normal to paper surface), l and d are the distance between optical center of vidicon and reference plane and that between optical center of vidicon and optical center of projecting device, respectively. From the schematic diagram of light path, it can be seen that due to object height change (that is, modulated by surface shape), light beams move from the point B to a new position (point A), the displacement from point B to point A carries point P's height information h.

A phase filed modulated by object surface is obtained from fringe images. The system needs to realize the treatment against grating phase. Common grating phase treatment methods include Moire method, Fourier transform profilometry (FTP), phase-shift method and wavelet analysis, *etc*. The commonly used methods are FTP and phase-shift method. In comparison with FTP, the phase-shift method features high accuracy, reduced calculation, low time consumption and good practicability. The system adopts the phase shift method to process fringe images, describes spatial distribution of grating filed via phases during measurement, and solves phases in fringe images to obtain the three-dimensional coordinate of a point. The phase-shift method increases several constant phases by shifting phases in the phase field of grating pattern, to obtain the fringe image of multiple gratings which will be used to solve phase field. By analyzing triangular relations of system structure, it is known that there is a relation shown in Equation (3) existed between object height profile h and grating deformation phase difference $\Delta\theta(m,n)$.

$$h = \frac{l(\theta_A - \theta_B)}{(\theta_A - \theta_B) + 2\pi d / \lambda_0} \tag{3}$$

Where, l is the distance between optical center of camera and reference plane, d is the distance between optical center of projecting device and that of vidicon, λ_0 is grating pitch.

According to optical triangular theory, attention should be paid to the following in light path:

(1) The optical axis of projector lens is normal to the reference plane;

(2) The projection axis of optical axis intersects with the reference plane; and

(3) The optical axis of projection fringe image of vidicon is parallel with the Y-axis of projecting device.

Obtain the height information of spatial point cloud according to above principle, acquire vertical coordinate and horizontal coordinate of individual points according to plane grating patterns, record fringe space as the horizontal coordinate and fringe height as the vertical coordinate, then the three-dimensional coordinate of a point can be obtained.

3. Volume Algorithm

3.1. Calculation of Bounding Box Volume

Bounding box is a method to solve the optimal bounding space of discrete point set, substitute circumscribed cuboid with a bounding box to meet actual demand of system. As shown in Figure. 3, since object placement is uncertain, each object point cloud has its own geometric features, while existing coordinate system may not be established based on these features, it is necessary to convert existing coordinate system, and the new coordinate system should reveal main change information data as far as possible. Such base vector conversion process is called "principal component analysis". Against the axial inspection problem of cuboid and cylinder during package testing, the system realizes identification of object features through principal component analysis. The principal component analysis algorithm removes redundancy and noise disturbance as much as possible to find out the so called "principal component" employing dimensionality reduction thought. Conduct Hotelling transform for point cloud coordinate to realize principal component analysis. As for Hotelling transform, based on statistical distribution, it finds out a set of optimal orthogonal vector basis to express original sample data, with minor error existed between new sample and original sample.

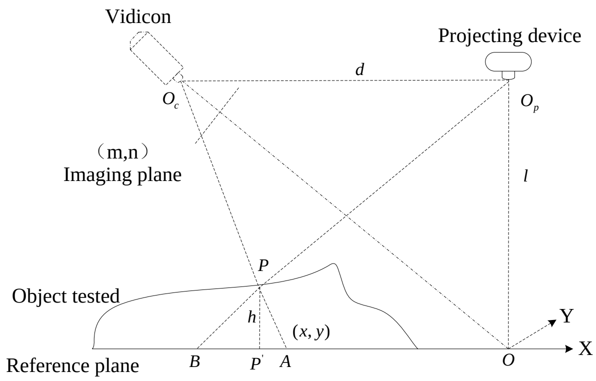
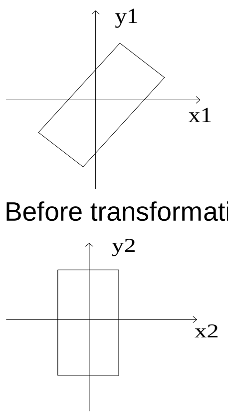


Figure 2. Light Path Figure of Grating Projection Measurement System



(1) Before transformation

(2) After transformation

Figure 3. Coordinate Transformation

The system extracts three-dimensional point cloud coordinates, applies Hotelling transform to three-dimensional eigenvectors. With coordinate of any point in point cloud taken as a three-dimensional vector $X_l = (x, y, z)^T$, calculate the mean vector, m_x and covariance matrix C_x of three-dimensional point cloud coordinate through vector X .

$$m_x = \frac{1}{L}\sum_{l=1}^{L} X_l \tag{4}$$

$$C_x = \frac{1}{L}\sum_{l=1}^{L} X_l X_l^T - m_x m_x^T \tag{5}$$

Where, L is the number of points in point cloud.

Since C_x is a 3×3-order real symmetric matrix, it has 3 eigenvectors. $A=(e_1e_2e_3)^T$ is C_x's eigenvector matrix. Point cloud coordinate system transformation calculation adopts the Hotelling transform shown in Equation (4), wherein A is a transformation matrix, X is the matrix before transformation, and Y is the matrix after transformation.

$$Y = A(X - m_x) \tag{6}$$

C_x is X's covariance matrix, and C_Y is Y's covariance matrix. Since A's row vector is C_x's eigenvector, diagonal elements in the covariance matrix C_Y of point cloud data in the new coordinate system are C_x's eigenvalue, the eigenvalue corresponded to one vector represents the contribution rate of matrix on that vector, as shown in Equation (8):

$$C_Y = AC_X A^T \tag{7}$$

$$C_Y = \begin{pmatrix} \lambda_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \lambda_N \end{pmatrix} \tag{8}$$

The direction of the new coordinate axis is in line with that of the eigenvector corresponded to the eigenvalue of maximum. In the new coordinate system, find out the maximal value and minimal value points on X-axis, Y- axis and Z-axis from point cloud data, that is $x_{\max}$, $x_{\min}$, $y_{\max}$, $y_{\min}$, $z_{\max}$ and $z_{\min}$ which form the AABB bounding box of object point cloud. Then the volume of point cloud bounding box can be calculated employing Equation (9). V is the volume of point cloud bounding box, $x_{\max}$, $x_{\min}$, $y_{\max}$, $y_{\min}$, $z_{\max}$ and $z_{\min}$ represent individual vertexes of bounding box.

$$V = (x_{\max} - x_{\min})(y_{\max} - y_{\min})(z_{\max} - z_{\min}) \tag{9}$$

3.2. Algorithm for Point Cloud Volume

In this paper, we calculate volume of closed point cloud based on point cloud tetrahedral grid subdivision. We obtain object point cloud using two vidicons, and joint it, so the point cloud is closed. Spatial point cloud tetrahedral subdivision is based on incremental Delaunays triangular subdivision algorithm. Incremental Delaunay optimization criteria is as follows: in three-dimensional case, the circumscribed sphere of any tetrahedron does not contain other points with point cluster. Before volume calculation, it is needed to conduct tetrahedral grid subdivision first, and specific steps of tetrahedral grid subdivision algorithm are given below:

(1) Input point cloud data;

(2) Establish the initial tetrahedron, surround the point cloud area to be subdivided;

(3) Insert one point P, and search the tetrahedron T with the circumscribed sphere contained point P. When insert the new point P, the following three conditions may occur: ① if the point P is within T, subdivide T into 4 small tetrahedrons; ② if the point P is at the outside of T, but within current tetrahedral grid, find out the division plane between T and P, then find out the tetrahedron contained P, subdivide that tetrahedron into 4 small tetrahedrons; ③ if P is at the outside of current tetrahedral grid, connect P with three vertexes of a visible surface of that grid to form a new tetrahedral grid;

(5) Divide a polyhedron into several tetrahedrons, avoid newly generated tetrahedrons being long and narrow as much as possible;

(6) If all points are inserted into current grid, remove large peripheral tetrahedrons; otherwise, repeat Step (3)-(5).

A volume algorithm improved on basis of Delaunay point-adding method is given in this paper, and the improvement is that it is needed to remove the peripheral tetrahedron. The peripheral tetrahedron is removed by calculating point cloud normal vector employing quadric surface fitting points and K nearest neighbor. For any tetrahedron, if the normal vector of individual points of current tetrahedron intersects the circumscribed sphere at a point (excluding that point itself), then the tetrahedron is a peripheral tetrahedron; otherwise, it is a inscribed tetrahedron. Only remove redundant tetrahedrons from current grid according to above determination criteria, can highly accurate point cloud volume be obtained.

Quadric surface fitting equation is as shown in Equation (10):

$$z = ax^2 + by^2 + cxy + dx + ex + f \tag{10}$$

Where, a,b,c,d,e,f are parameters to be determined.

For a given point $(x_i, y_i, z_i) i = 1,2,\cdots,N$, minimize overall error Q.

$$Q = \sum_{i=1}^{N} [z_i - (ax_i^2 + by_i^2 + cx_i y_i + dx_i + ey_i + f)]^2 \tag{11}$$

In order to solve parameters to be determined, we may solve extremums which can be transformed into a 6-variables function $Q(a,b,c,d,e,f)$, that is, a,b,c,d,e,f meet the equation below:

$$\frac{\partial Q}{\partial a} = \frac{\partial Q}{\partial b} = \frac{\partial Q}{\partial c} = \frac{\partial Q}{\partial d} = \frac{\partial Q}{\partial e} = \frac{\partial Q}{\partial f} = 0 \tag{12}$$

Solve Equation (12) to obtain individual parameters to be determined. Solve the normal vector of any point according to the partial derivative of the two-dimensional surface equation fitted at that point, and then unify normal vectors.

If four vertexes of one tetrahedron are A(x_0, y_0, z_0), B(x_1, y_1, z_1), C(x_2, y_2, z_2) and D (x_3, y_3, z_3), then its volume V can be calculated employing the method shown in Determinant (13).

$$V = \frac{1}{6}\begin{vmatrix} x_0 & y_0 & z_0 & 1 \\ x_1 & y_1 & z_1 & 1 \\ x_2 & y_2 & z_2 & 1 \\ x_3 & y_3 & z_3 & 1 \end{vmatrix} \tag{13}$$

4. Experiment and Analysis

4.1. Experimental Platform

Experimental platform: the projector adopted is NEC NP-L51W+ with luminance of 500 lumen, the max. resolution of 1920×1080 and projection distance of 0.52-3m, and it has manual zooming and focusing function. With measured distance of 500mm-100mm and max. area of object of 500*500mm, a 1000000-pixel camera is needed. The FL2G-13S2C industrial camera with 1300000 pixel produced by Point Gray company is used in our work. The camera obtains three-dimensional point cloud at 60cm away from a object. According to relevant standards, the accuracy of 0.1mm is acceptable.

4.2. Experimental Results

In order to verify feasibility of the package test algorithm based on bounding box, obtain clustered point cloud data to carry out experiment. Point cloud bounding box obtainment result is as shown in Figure.4, wherein what shown in the first row are original image, and in the second row are bounding box test results. From bounding box test results, it can be seen that Hotelling transform favorably analyzed point cloud set's principal component, and generated a bounding box based on geometric shape of point cloud. With the circumscribed cuboid substituted by a bounding box, the package test result is very favorable.

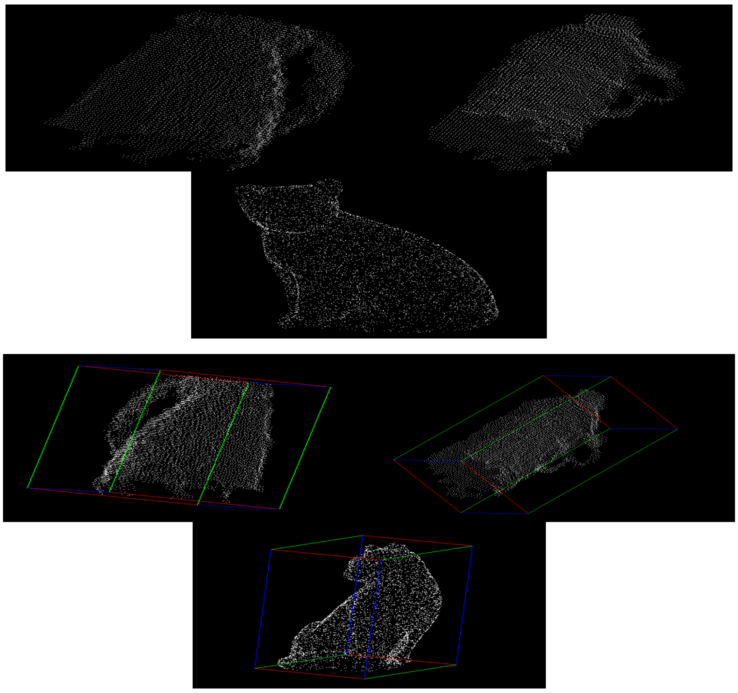
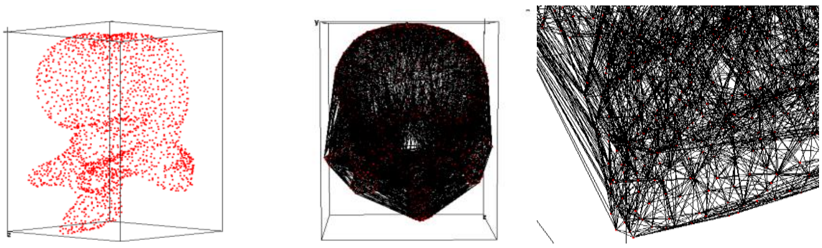
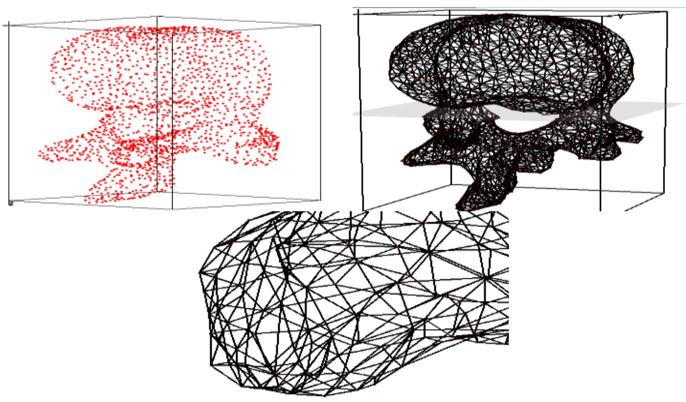


Figure 4. Point Cloud Bounding Box Obtainment



(a) Initial point cloud (b) Subdivided grid (c) Local tetrahedral grid



(a) Initial point cloud (b) Subdivided grid (c) Local tetrahedral grid

Figure 5. Point Cloud Subdivision Algorithm Example

In the point cloud subdivision algorithm example shown in Figure. 5, in order to verify improvement effect of the algorithm described in this paper, during experiment, omit the step "remove peripheral tetrahedrons" at first and just conduct preliminary tetrahedral subdivision. The point cloud used in volume calculation and test is as shown in Figure. 6 (an animal spine model contained 1932 points), what shown on the right is a tetrahedral grid generated by scattered point cloud.

Experimental results showed that tetrahedral subdivision is just the division against convex hull, after tetrahedral grid formation, there are many tetrahedrons which are redundant data. After peripheral tetrahedrons are removed according to above algorithm, we obtained the grid chart shown in Figure. 7.

The set of all Delaunay tetrahedrons form the point cloud topological structure, calculate the volume of all tetrahedrons which is the volume of the area contained by point cloud.

4.3. Result analysis

Calculate volume using three groups of point cloud, and calculated results are as given in Table 2. From these results, it can be known that calculation accuracy rate could reach up to 95%. Based on the principle of grating projection system, in case that point cloud is a set of points on object surface, algorithm complexity approaches $O(n\lg n)$. Calculate spatial point cloud volume based on above-mentioned spatial grid reconstruction method, and make comparison with traditional Poisson reconstruction method. Poisson reconstruction method reconstructs grid surface according to Poisson equation solving. It estimates grid model's indicator parameters and contour surface by solving Poisson equation, and then realizes surface reconstruction employing seamless trigonometric approximation. Poisson method has such advantage that the surface constructed is smooth. Reconstruct grids using the algorithm described in this paper and Poisson method, respectively; compare time consumption of these two spatial grid reconstruction methods, as shown in Table 2. For the three groups of point cloud employed in experiment, time consumption of the algorithm described in this paper is 21.2%~43.9% of that of Poisson method.

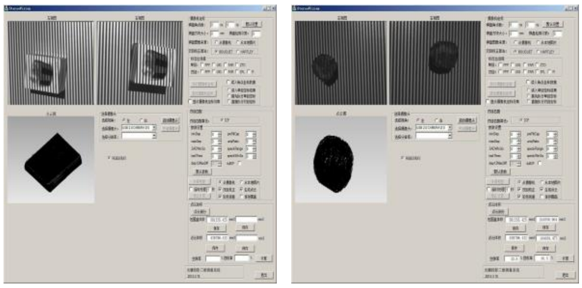
Table 1. Point Cloud Volume Calculation Result

No.	$V_o\ /\ mm^3$	$V\ /\ mm^3$	$\delta\ /\ \%$
1	27952.8	26384.648	5.07
2	58990.5	61591.981	4.41
3	36885.5	36173.610	1.93

Table 2. Time Consumption Comparison

Experimental point cloud	Time consumption of Poisson method/s	Time consumption of the algorithm described in this paper/s
1	3.259	0.691
2	4.403	1.933
3	80.402	30.553

Establish the actual measurement system according to the measurement principle described above, and conduct experiment taking the pastry in above table as the experiment sample. Experimental interface of system is as shown in Figure. 7(a). First calculate the volume of point cloud and the volume of bounding box of selling package, which are calculated to be 538796.432 mm^3 and 581335.425 mm^3, respectively.



(a) Package test (b) Commodity Test

Figure 8

The point cloud obtained in Figure.7 (b) is a pastry point cloud, recalculate the volume of current point cloud and the volume of current bounding box, which are calculated to be 164639.475 mm^3 and 244550.904 mm^3, respectively. Based on parameters obtained from above process, calculate voidage (32.6%) and volume fraction (30.5%) to realize commodity over-package test. According to provisions on pastry limited packaging in Table 1, the package of that pastry meets requirements.

5. Conclusion

Against the commodity over-package test problem, a commodity package test system based on grating projection measurement was proposed in this paper. The system adopts a new measurement method in which the volume of object point bounding box is calculated to substitute that of the circumscribed cuboid of an object, proposes the method to calculate point cloud volume of a three-dimensional object during package test, adds a new characteristic index (volume fraction), and realizes non-contact and rapid package test. The method using a bounding box to substitute manual measurement of circumscribed cuboid provides more reference basis for future package test research. It significantly reduces measurement time using contact-free feature and high accuracy of machine vision, and has high practicability.

References

[1] He, J., Geng, Y., Wan, Y., Li, S., and Pahlavan, K. **(2013)**. A cyber physical test-bed for virtualization of RF access environment for body sensor network. Sensors Journal, IEEE, 13(10), 3826-3836.

[2] Lv Z, Tek A, Da Silva F . Game on, science-how video game technology may help biologists tackle visualization challenges[J]. PloS one, **(2013)**, 8(3): 57990.

[3] Su T, Wang W, Lv Z . Rapid Delaunay triangulation for randomly distributed point cloud data using adaptive Hilbert curve[J]. Computers & Graphics, **(2016)**, 54: 65-74.

[4] Jinyu Hu, Zhiwei Gao and Weisen Pan. Multiangle Social Network Recommendation Algorithms and Similarity Network Evaluation[J]. Journal of Applied Mathematics, 2013 **(2013)**.

[5] Shuang Zhou, Liang Mi, Hao Chen, Yishuang Geng, Building detection in Digital surface model, 2013 IEEE International Conference on Imaging Systems and Techniques (IST), Oct. **(2012)**.

[6] Jie He, Yishuang Geng, Kaveh Pahlavan, Toward Accurate Human Tracking: Modeling Time-of-Arrival for Wireless Wearable Sensors in Multipath Environment, IEEE Sensor Journal, 14(11), 3996-4006, Nov. **(2014)**.

[7] Lv Z, Halawani A, Fen S . Touch-less Interactive Augmented Reality Game on Vision Based Wearable Device[J]. Personal and Ubiquitous Computing, **(2015)**, 19(3): 551-567.

[8] Guanqun Bao, Liang Mi, Yishuang Geng, Mingda Zhou, Kaveh Pahlavan, A video-based speed estimation technique for localizing the wireless capsule endoscope inside gastrointestinal tract, 2014 36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), Aug. **(2014)**.

[9] Degui Zeng, Yishuang Geng, Content distribution mechanism in mobile P2P network, Journal of Networks, 9(5), 1229-1236, Jan. **(2014)**.

[10] Gu W, Lv Z, Hao M. Change detection method for remote sensing images based on an improved Markov random field[J]. Multimedia Tools and Applications, **(2015)**: 1-16.

[11] Chen Z, Huang W, Lv Z. Towards a face recognition method based on uncorrelated discriminant sparse preserving projection[J]. Multimedia Tools and Applications, **(2015)**: 1-15.
[12] Jinyu Hu and Zhiwei Gao. Distinction immune genes of hepatitis-induced heptatocellular carcinoma[J]. Bioinformatics, **(2012)**, 28(24): 3191-3194.
[13] Su T, Wang W, Lv Z . Rapid Delaunay triangulation for randomly distributed point cloud data using adaptive Hilbert curve[J]. Computers & Graphics, **(2016)**, 54: 65-74.
[14] Gu W, Lv Z, Hao M. Change detection method for remote sensing images based on an improved Markov random field[J]. Multimedia Tools and Applications, **(2015)**: 1-16.
[15] Lv Z, Tek A, Da Silva F . Game on, science-how video game technology may help biologists tackle visualization challenges[J]. PloS one, **(2013)**, 8(3): 57990.
[16] Chen Z, Huang W, Lv Z. Towards a face recognition method based on uncorrelated discriminant sparse preserving projection[J]. Multimedia Tools and Applications, **(2015)**: 1-15.
[17] Jiang D, Ying X, Han Y. Collaborative multi-hop routing in cognitive wireless networks[J]. Wireless Personal Communications, **(2015)**: 1-23.
[18] Lv Z, Tek A, Da Silva F . Game on, science-how video game technology may help biologists tackle visualization challenges[J]. PloS one, **(2013)**, 8(3): 57990.

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