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An Algorithm for Inspecting Self Check-in Airline Luggage Based on Hierarchical Clustering and Cube-fitting

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Abstract: Airport passengers are required to put only one baggage each time in the check-in self-service so that the baggage can be detected and identified successfully. In order to automatically get the number of baggage that had been put on the conveyor belt, dual laser rangefinders are used to scan the outer contour of luggage in this paper. The algorithm based on hierarchical clustering and cube-fitting is proposed to inspect the number and dimension of airline luggage. Firstly, the point cloud is projected to vertical direction. By the analysis of one-dimensional clustering, the number and height of luggage will be quickly computed. Secondly, the method of nearest hierarchical clustering is applied to divide the point cloud if the above cannot be distinguished. It can preferably solve the difficult issue like crossing or overlapping pieces of baggage. Finally, the point cloud is projected to the horizontal plane. By rotating point cloud based on the centre, its minimum bounding rectangle (MBR) is obtained. The length and width of luggage are got form MBR. Many experiments in different cases have been done to verify the effectiveness of the algorithm. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Self-service Baggage Check-in System; Point Cloud; One-dimensional Clustering; Nearest Hierarchical Clustering; MBR.

1. Introduction

With the promotion and application of civil self-service, 21 % of travelers have used self-service up to 2012 in China. It saves about one hundred million Yuan for the civil aviation every year, and greatly reduces the passengers' check-in time while waiting in line. However, passengers with baggage still need to queue for the baggage handling. The self bag drop system is an automated system which is developed to solve the problem. Automatically checking the number of airline luggage put in the bag drop system is the key issue of the system, which must be solved.

In the process of self-service for baggage, passengers can only put in a piece of luggage per person. If multiple pieces of luggage are put in, the dimension and weight of baggage cannot be calculated and the airport cannot allow the consignments. Stereo vision and laser ranging are mainly used to inspect airline luggage number. As the laser ranging is more stable than stereo vision which is easily affected by the external environment, this paper intends to adopt a two-dimensional laser range finder to inspect airline baggage number.

Reference [1] described some typical clustering algorithms and had simulation experiments in the correct ratio and operating efficiency by a comparative analysis. The difficulties and shortcomings of clustering algorithms were given in the end. Reference [2] applied a 2D laser scanner to dynamically measure metro rail gauge. It suggested that dynamic laser ranging has good stability. In references of [3, 4] the three-dimensional laser data of the surface was got by some auxiliary organizations and 3D models were built. But the speed was relatively slow while distortion was comparatively large. Reference [5] used a 2D laser rangefinder to calibrate the testing platform with the error about 10 mm. Its accuracy was low. For checking the number of airline baggage, it had lots of uncertainty factors in the bag shapes and placing way. In order to avoid laser detection blind, the layout of the laser system is very important. And it requires high accuracy, good stability and fast speed.

This paper is proposed by using laser rangefinder to scan the moving baggage and obtain the surface position information of the luggage. Theoretical analyses and experimental results are given based on dual laser system layout. Firstly the laser point cloud data of luggage surface is preprocessed to remove the background and noise. Then the methods of one-dimensional clustering and hierarchical clustering are used to classify the luggage surface data [1]. Some results about inspecting the number of baggage are given. The algorithm is provided with the feature of high accuracy, good stability, strong practicability, which can rapidly inspect whether various airline luggage dimensions meet the requirement of self - service bag drop system.

2. System Structure and Principles

Self-service baggage check-in equipment is shown in Fig. 1.

Fig. 1. Self-service baggage check-in equipment.

The left part is luggage channel section, and the right part is check-in system. The luggage channel section is comprised of the baggage drop zone, the scanning area and the detection zone. The baggage drop zone is outside the entrance, baggage scanning area is between the entrance and the shelter blinds, and the luggage detection zone is within the blocking curtain. Baggage passes through these three areas in a proper sequence. Dual lasers are installed above the baggage scanning area. Baggage's surface will be scanned in every cycle when it goes into the scanning area. When the baggage is completely in the detection zone, the 3D laser data of the baggage outer surface will be obtained.

2.1. The Installation of Laser

The system uses a dual laser system to detect the number of luggage. Assume that the horizontal cross section is X axis, the vertical direction is Y axis and the luggage channel direction is Z axis as shown in Fig. 2. Each laser rangefinder scans down in the height of H from the belt surface, and with the angle of α and β from X-axis. There is a distance of L between laser and the center channel position in X- axis. Lasers respectively measure the left and right outlines of the baggage.

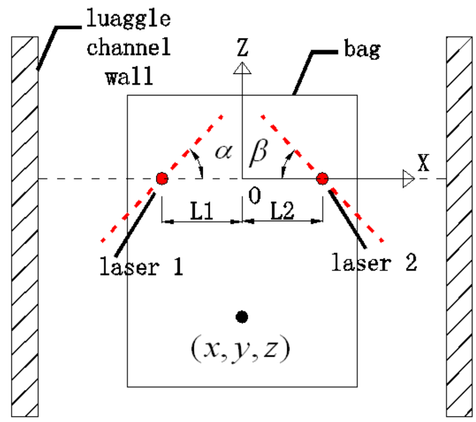


Fig. 2. Installation of dual lasers over top view.

For a point of $A(x, y, z)$ on the surface of the baggage, it is assumed that the distance from laser rangefinder to A is S, its launch angle is θ, the surface speed of conveyor belt is v, and the running time is t. In the laser 1 system, there is:

$$\begin{cases} x_1 = -S_1 \cos\theta_1 \cos\alpha - L \\ y_1 = H - S_1 \sin\theta_1 \\ z_1 = \int \mathrm{v}dt + S_1 \cos\theta_1 \sin\alpha \end{cases}, \quad (1)$$

In the laser 2 system, there is:

$$\begin{cases} x_2 = -S_2 \cos\theta_2 \cos\beta + L \\ y_2 = H - S_2 \sin\theta_2 \\ z_2 = \int vdt - S_2 \cos\theta_2 \sin\beta \end{cases}, \quad (2)$$

As the photon emitted from laser sensor is easily absorbed and attenuated by the object which results some interference data [6], and the laser rangefinder has inherent measurement error, so the laser point cloud data must be pretreated.

2.2. The Preprocessing of Laser Data

There is some interference data returning from laser rangefinder. Their characters are relatively obvious, which are usually some isolated points or isolated group consisting of a few points.

The methods of pretreatment of laser data can use lateral filtering, vertical filtering and points spacing filtering. Lateral filtering method is based on analyzing the distribution of the laser data in the lateral direction. If the lateral distance between two points is greater than a certain threshold, a breakpoint occurs and the point is discarded. Vertical filtering method is similar to the lateral filtering. It is according to the analysis of the laser data in the vertical axis. Spacing filtering determines the distance between two points as the breakpoint. Because lasers are mounted vertically, the lateral spacing of laser data satisfies “average distribution”. So the lateral filtering method is more suitable in pretreatment.

To calculate the maximum distance of laser data in lateral direction, it is supposed that the laser is mounted above the luggage channel shown in Fig. 3. The luggage channel width is known as D, and the origin is below the laser on the conveyor belt. From the picture, there is $d_1 > d_2$, so the maximum lateral spacing is d_1. If laser emission angles of S1 and S2 are θ_1 and θ_2 respectively, and the angular resolution of the laser is $\Delta\theta$, there is:

$$\begin{cases} \theta_1 \approx \arctan(2H/D) \\ \theta_2 = \theta_1 + \Delta\theta \\ d_1 = H\cot\theta_1 - H\cot\theta_2 \end{cases}, \quad (3)$$

The maximum lateral spacing of a single laser is assumed as X, and the angle to the X axis is ϕ. When equation (3) is converted to the dual laser system, there is:

$$X = \frac{L + D/2}{\cos\phi} - H\tan(\arctan\frac{H\cos\phi}{L + D/2} + \Delta\theta), \quad (4)$$

As the laser rangefinder has inherent measurement error, the threshold value of the lateral filter is:

$$\mathrm{H}_x = X + Er, \quad (5)$$

where Er is the laser measurement accuracy. After pretreatment laser point cloud data has to match and fuse with dual lasers. Finally, 3D point cloud data is got by fusing dual lasers data.

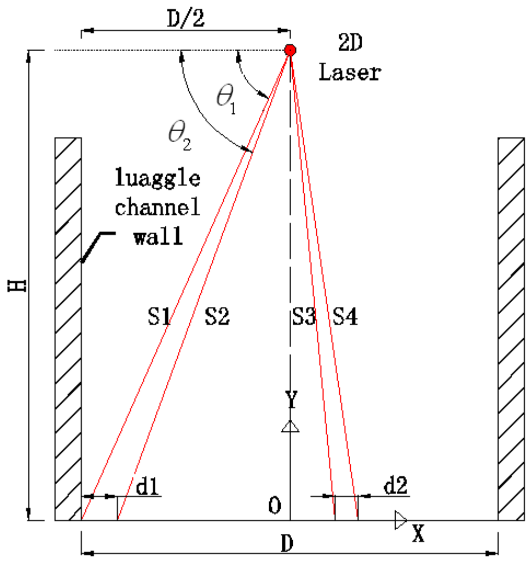


Fig. 3. The error analysis of single laser in X direction.

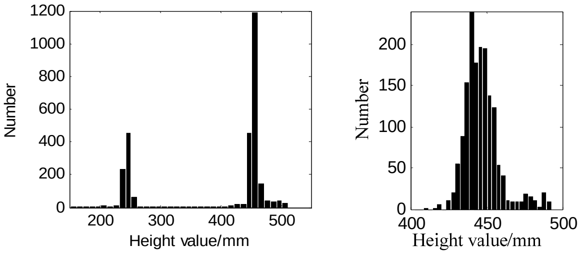
3. The Clustering Segmentation of Laser Point Cloud

Due to the cross-mounting of dual lasers, the 3D point cloud data is overlapping. Surface data of each luggage is a whole, and it can be considered as a “class”. By clustering segmentation, the number of luggage will be determined. For some putting luggage of obvious features, such as inconsistent height, 3D laser point cloud is firstly analyzed in different dimensions. It can reduce the inspection time.

3.1. One-dimensional Cluster Analysis

By analyzing the height of the luggage and the way of putting it can quickly analysis and detect the number of luggage that travelers put in. The height data of multiple pieces of luggage is of inevitable differences, so there will be multiple peaks through statistical analysis in height dimension. If the distance between the peaks is distant, it can be considered as multiple pieces of luggage. When pieces of luggage are placed side by side or front and back, the laser point cloud in the X and Z directions will appear multiple peaks. It can be determined as multiple pieces of luggage by the distance between the peaks.

The statistical distribution of two different heights data from dual lasers is shown in the Fig. 4(a). Among it, the horizontal axis represents the height of the baggage, and the vertical axis is the number of the laser spot. The pitch of this distribution is 10 mm. As can be seen from the figure, there are two peaks. The small number of distribution points is the baggage side. By calculating the distance between the peaks the number of luggage can be determined. The principle is the same in X and Z directions.



(a) Two bags (b) One bag

Fig. 4. Height distribution of the laser point cloud data.

The height distribution of one bag is shown in the Fig. 4(b). There are some convex hulls in the uppermost part of height data which need to be filtered. So size of a general baggage handle is as the threshold. After filtering the convex hulls by the method of threshold, the height data obeys N(446.6188 14.55622) of Normal Distribution. Take 446.6188 as the height value, while actual luggage's height is 440 mm. The measuring error of this algorithm is within 10 mm.

3.2. Nearest Hierarchical Clustering

For similar height of baggage, it is difficult to draw the number of luggage through a simple analysis of the point cloud data. Because the two lasers are installed crossing, there are a plurality of intersections in 3D laser data after fusion, as shown in Fig. 5. Those intersections combine the surface laser data of the luggage as a whole. After choosing a point on the surface of the luggage and starting to search at the maximum spacing of X_1 or X_2, it will traverse all points of the luggage. This method is the nearest hierarchical clustering searching method. The computational complexity is $O(n^2)$, so it meets the classification for small point cloud. The distance between $A_i(x_1,...,x_n)$ and $A_j(y_1,...,y_n)$ is supposed to d_{ij}. From the calculating of Euclidean distance, there is:

$$d_{ij}=\sqrt{(x_1-y_1)^2+(x_2-y_2)^2+...+(x_n-y_n)^2}\,, \quad (6)$$

Because the laser point cloud is three-dimensional data, so n takes 3. The nearest distance similarity between two clusters of Γ_i and Γ_j is defined as follows:

$$\Delta(\Gamma_i,\Gamma_j)=\min_{\substack{x\in\Gamma_i\\ \tilde{x}\in\Gamma_j}}\delta(x,\tilde{x})\,, \quad (7)$$

Initially, $\Gamma_j=x_j$, $\forall j\in I$, and $I=\{j|_{j=1,2,...,N}\}$. In (7), Γ_j is the set of each cluster, and N is the number of samples. Each sample is set as a class initially. The steps of the algorithm are as follows:

Step 1: Find one pair of clusters of Γ_i and Γ_k meeting the condition of $\Delta(\Gamma_i,\Gamma_k)=\min_{\forall j,l\in I}\Delta(\Gamma_j,\Gamma_l)$ in the set of $\{\Gamma_j\mid j\in I\}$. $\Delta(\Gamma_i,\Gamma_k)$ is the nearest distance similarity of Γ_i and Γ_k.

Step 2: If $d_{ik}\le\sqrt{\mathrm{H}_x^2+\mathrm{H}_y^2+\mathrm{H}_z^2}$, put Γ_i into Γ_k, and remove Γ_i. H is the filter threshold for each dimension.

Step 3: i is removed from I. If the cardinal number of I is equal to 2 or the distance between all points satisfies $d_{ik}>\sqrt{\mathrm{H}_x^2+\mathrm{H}_y^2+\mathrm{H}_z^2}$, the calculation is terminated; Otherwise turn to step 1.

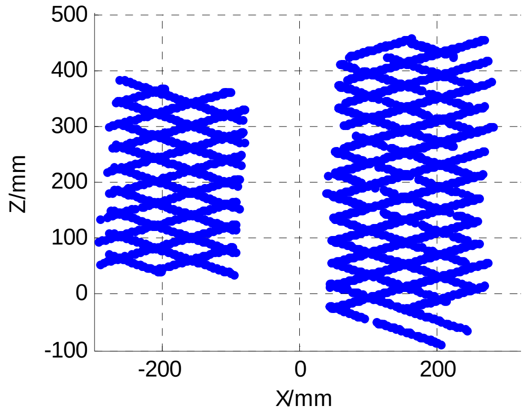


Fig. 5. Laser point cloud of multiple pieces of luggage.

3.3. Cube-fitting of Laser Point Cloud

Airline luggage dimension is inspected with the maximum size, so this paper adopts the maximum size for luggage cube-fitting to get the minimum enclosing cube from the three-dimensional laser data. In order to reduce the computational complexity, cube-fitting is transformed to the horizontal plane and longitudinal fitting. The method of minimum area bounding rectangle is used in horizontal plane. Its idea is as follows:

Step 1: Seek out boundary points of the maximum convex polygon, and make them as the new boundary points.

Step 2: With the coordinate origin as the center, rotate the coordinate system in fixed order and save the rotation.

Step 3: Calculate and save the area and number of minimum bounding rectangle. The number is correspondence with the rotation angle.

Step 4: Compare the area resulting from minimum bounding rectangle, where the smallest area bounding rectangle is the minimum area bounding rectangle.

There are some boundary points of a soft luggage in dual laser system, as shown in Fig. 6(a) after coinciding two laser's data. Among them, the pink dot is the laser 1 data, the blue dot is the laser 2 data, and the red bounding rectangle is the minimum bounding rectangle. In order to reduce the computational complexity of the software, the maximum convex polygon is calculated firstly to obtain the new boundary points. The solution of minimum bounding rectangle is based on them. Obviously, the minimum bounding rectangle in left picture is not the minimum area bounding rectangle. So the way of rotating the coordinate system is employed in searching for the minimum bounding rectangle area. The result of MABR is shown in Fig. 6(b).

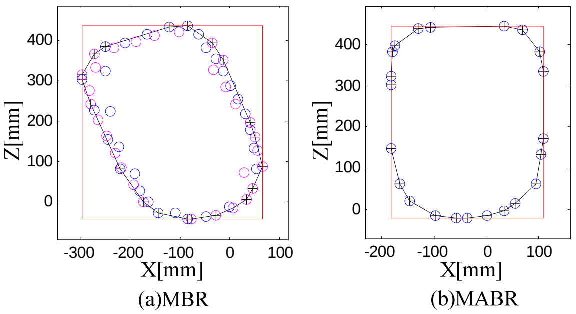


Fig. 6. Method of minimum bounding rectangle.

4. Results and Analysis of Experiments

4.1. The Preprocessing of Laser Data

There is a lot of noise in luggage surface data obtained by laser rangefinders, as shown in the left of Fig. 6. Since the lasers are installed vertically downward, so the system uses lateral filtering to preprocess. H_x is the threshold of lateral filter. Finally, the single laser dot cloud data after preprocessing is shown in the right of Fig. 7.

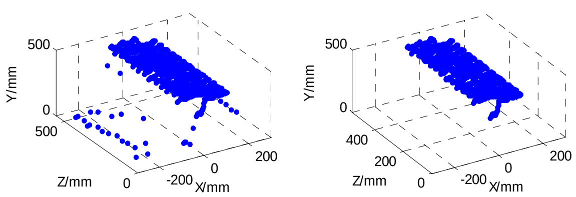


Fig. 7. Preprocessing of a single laser data.

4.2. The Check of the Number of Luggage

The method of one-dimensional clustering is used to analyze the baggage data in height, lateral and longitudinal directions. It can identify the number of luggage quickly. From the results of experiments, the horizontal and vertical placements of luggage are shown in the left of Fig. 8, and the projection data in horizontal and vertical directions is shown in the right of Fig. 8. By the method of one-dimensional clustering, if the number of consecutive and multiple distributions are greater than the threshold, it is a bunch of data. If the interval between clusters is relatively large, it is considered as multi-cluster data which represents multiple pieces of luggage.

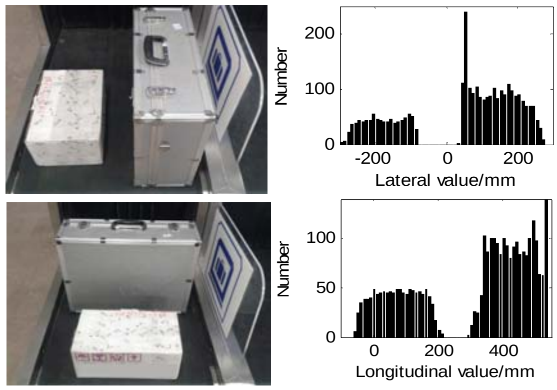


Fig. 8. Distributions of laser data in horizontal and vertical directions.

From the search method of nearest hierarchical clustering, initially consider each sample as a class. Then search for each point, and take its nearest point together to form a new class. Repeat the process above, until the distance between classes is greater than the filter threshold. The experimental results are shown in Fig. 9.

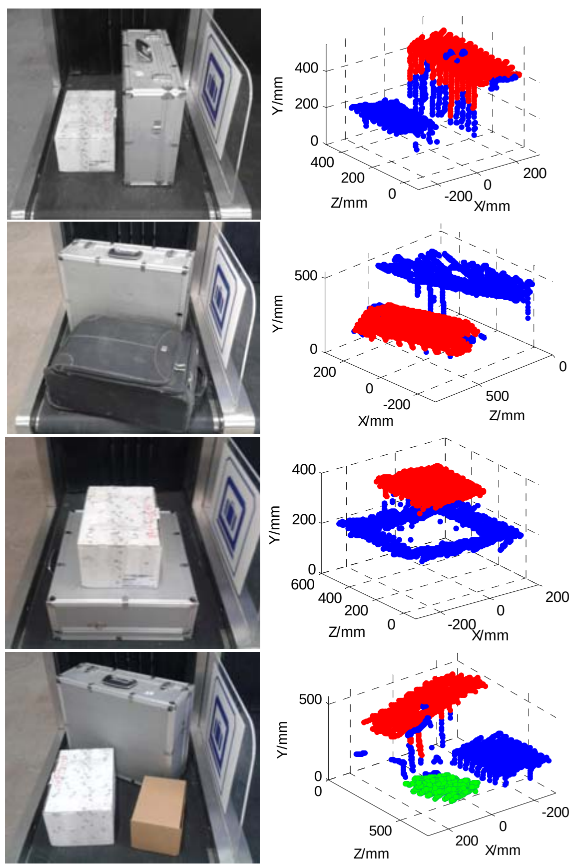


Fig. 9. Clustering segmentation for laser point cloud.

In the Fig. 9, the red is one class, the green is another class, and the blue is the third class. A clustering can be considered as a baggage by the number of laser dots in it. So the number of the putting luggage will be checked out from the amount of clustering.

4.3. Experiments of the Dimension Measurement for Luggage

There is a conventional luggage of length 540 × width 440 × height 195 mm^3 taken as the measurement object. 10 groups of length and width measurements are shown in Table 1. Experimental results show that the measuring error of this algorithm is within 10 mm.

Table 1. Measurement data of single laser and dual laser system.

	Width (Unit: mm)		Length (Unit: mm)	
Theoretical value	440		540	
No.	**Measure-ments**	**Absolute error**	**Measure-ments**	**Absolute error**
1	441.0430	1.0430	544.5518	4.5518
2	441.6225	1.6225	538.4878	-1.5122
3	439.6322	-0.3678	536.3218	-3.6782
4	440.8780	0.8780	546.0739	6.0739
5	442.1224	2.1224	547.7181	7.7181
6	432.8980	-7.1020	544.3719	4.3719
7	449.0881	9.0881	545.6062	5.6062
8	448.1761	8.1761	542.2725	2.2725
9	432.0473	-7.9527	543.2496	3.2496
10	433.9200	-6.0800	545.0799	5.0799

Measurements for four different shapes of luggage in height direction were shown in Fig. 10 and Table 2. Among them, bag 1 is white, bag 2 is black and bag 3 is brown. Their surfaces are relatively flat. Bag 4 is a soft luggage whose surface is very uneven.

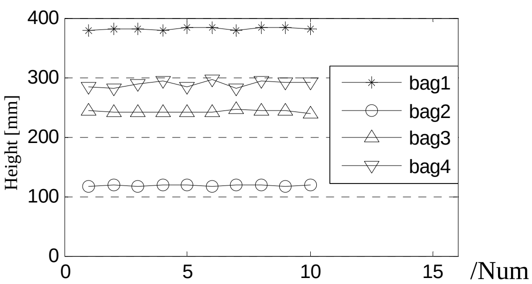


Fig. 10. Measurement of luggage height.

The results show that the algorithm won't be affected by the color of the luggage and the measuring error is within 10 mm. The convex-hull data of luggage surface can be effectively eliminated and the height measurement is more real and effective.

Table 2. Measurement of luggage height (Unit: mm).

Bag No.	Actual height	Average height	Average error
1	390	381.2	8.7
2	130	120.9	9.1
3	240	243.5	3.5
4	290	288.8	4.8

5. Conclusions

The algorithm for inspecting the number and dimension of airline luggage integrates one-dimensional clustering, nearest hierarchical clustering and cube-fitting methods. One-dimensional clustering method has the fast characteristic, and can distinguish simple placements of luggage and obtain the height of the luggage. The method of nearest hierarchical clustering is to solve crossing or overlapping placements of luggage. The algorithm can effectively identify the number of putting luggage. The length and width of luggage are got by the method of cube-fitting. Many in different cases have been done to verify the effectiveness of the algorithm. From the experiments, this algorithm accelerates the check-in speed for passengers using self-service baggage equipment.

Acknowledgements

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Sensors & Transducers, Vol. 168, Issue 4, April 2014, pp. 287-293

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