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Implementation of Luggage Measurement System Based on Binocular Camera

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Abstract. The rapid development of civil aviation has caused a surge in the air consignment business. Effective use of luggage-related information will significantly improve the efficiency of packaging, sorting, and transporting. Previous studies related to measurement have paid more attention to the accuracy of the results, but little research has been done on how to quickly obtain the measurement results. We propose a vision measurement system for luggage based on binocular structured light cameras to obtain scene data to measure the luggage. The scene data is preprocessed into point cloud data, and the point cloud processing method is used to obtain the necessary three-dimensional information. Then the point cloud is projected, compressed into an image, and other information is extracted by image processing methods, which significantly reduces the amount of calculation. Sufficient experiments show that the system can retrieve luggage-related information effectively and stably.

Keywords: 3D point cloud, measurement system, computer vision, luggage

1. Introduction

With the rapid development of civil aviation and the fast-growing number of flights and passenger flow year by year, the pressure on luggage consignment business increases. The information and intelligent management of luggage consignment is a critical way to improve the efficiency of the consignment system. Fig. 1 shows the common types of checked parts of luggage. The current air consignment system has shortcomings such as the high total cost, low technical equipment, and low operating efficiency. Moreover, the use of information such as the category and geometric dimensions of checked luggage has been in a weak link for a long time. Effective use of this information will significantly improve the efficiency of luggage packaging, sorting, and transporting. Then the accurate extraction of luggage category, size, volume, posture, and other information is the critical link, which provides a vital information basis for the operation of the automated consignment system.

Fig. 1: Example of common luggage type

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Many researchers have conducted active research on luggage measurement. Gao et al.[1] proposed a hierarchical evaluation method based on point cloud data. Firstly, the rough classification is carried out according to the mean square error of luggage surface depth value. Then the point cloud is adaptively clustered according to the grid similarity to fit further the number and area of medium and high-level units for fine classification. Li et al.[2] proposed a geometric size measurement system applied to the logistics industry, closely combining the parallax three-dimensional reconstruction algorithm with the feature extraction and positioning algorithm, which can perform the measurement in complex scenes. Zhang et al.[3] proposed a binocular stereo size measurement method based on an improved SURF(Speeded Up Robust Features) registration algorithm, and parallax optimization and edge extraction algorithms obtain the accurate three-dimensional space to realize non-contact size measurement. Chelishchev et al.[4] proposed a minimum bounding box estimation algorithm for three-dimensional point clouds. First, a preprocessing operation is performed to remove convex polyhedral faces near the edge of the measured object. Moreover, excluding them in the convex polyhedral data set can save calculation time. Then based on the convex hull operation, the minimum boundary surface of the convex polyhedron is established.

As can be seen from the above introduction, most measurement researches focus on camera calibration, feature point extraction, stereo matching, 3D reconstruction, and so on, but there is little research on how to quickly obtain the measurement results. Meanwhile, most previous methods have problems such as high algorithm complexity, expensive sensors, and limited accuracy. This paper designs a system that can detect and measure baggage in general scenarios. It processes the three-dimensional scene data obtained by the binocular structured light camera into point cloud data. It extracts the depth information of the measured object from the point cloud data. Then the point cloud data is compressed into a picture to achieve the purpose of positioning and geometric size measurement of the measured object. Experiments have proved that the measurement system has the advantages of being fast, efficient, and stable.

2. Theoretical Background

2.1. Binocular Parallax Model

The measurement system obtains image information through the camera and performs binocular matching through the binocular parallax model to restore the spatial three-dimensional structure information[5], and the typical form is a binocular structured light camera[6].The principle of using structured binocular light for three-dimensional measurement is to project a series of coded patterns onto the object's surface to be measured through a projector[7]. And then use the left and right cameras to capture the distorted fringe image of the object's surface (the distortion of the fringe contains the three-dimensional information of the object surface). Then obtain the mapping relationship between the left and right camera pixels according to the relevant decoding and matching algorithms, and use the triangulation method to obtain the three-dimensional point information corresponding to the object pixels[8].

The ideal binocular parallax model is shown in Fig. 2.In the model, the optical axes of the left and right cameras are parallel, and the corresponding images do not have a rotation relationship. The two cameras are generally fixed on the same plane. Define the left camera as the world coordinate system, $P_1(u_l, v_l)$ and $P_2(u_r, v_r)$ are the projection points of a specific point $P(x_c, y_c, z_c)$ in the space on the left and right camera image planes, f is the focal length of the camera, and the distance between the left and right camera optical axes is B. According to the geometric triangle relationship, Equation (1) can be obtained. According to the definition of parallax as the difference $d = (u_l - u_r)$ between the horizontal coordinates of the left and right images, the coordinates of point P can be calculated, as shown in (2).

$$u_l = f\frac{x_c}{z_c}; u_r = f\frac{(x_c - B)}{z_c}; v_l = v_r = f\frac{y_c}{z_c} \tag{1}$$

$$x_c = \frac{Bu_l}{d}; y_c = \frac{Bv_l}{d}; z_c = \frac{Bf}{d} \tag{2}$$

In the binocular field of view, if the imaging position of the same spatial point can be found in the two images, the parallax value of the point can be obtained, and then the parallax value of the point can be calculated based on the parallax and the value of some camera parameters. Three-dimensional coordinates in space, that is to say, the three-dimensional information of the spatial point can be recovered from the binocular image.

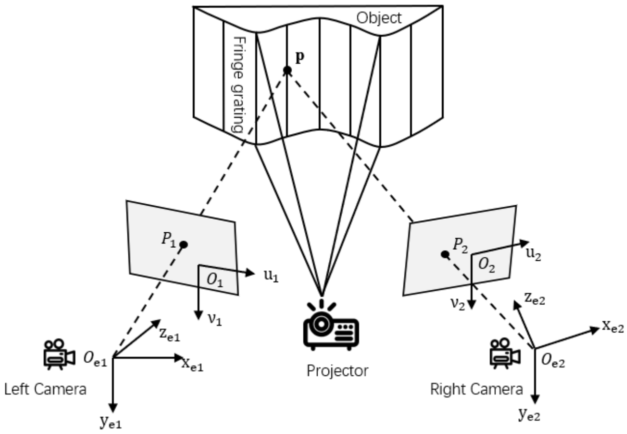


Fig. 2: Binocular structured light camera model

2.2. RANSAC Algorithm

The Random Sample Consensus(RANSAC) algorithm proposed by Fischler et al. [9] is a general parameter estimation method designed to deal with many outliers in the input data. The algorithm is widely used in computer vision and mathematics[10], such as straight-line fitting, plane fitting, transformation matrix calculation between images or point clouds, fundamental matrix, etc. The RANSAC is a resampling technique that uses an iterative method to estimate the parameters of the mathematical model from a set of observed data containing outliers. The core idea of the algorithm is randomness and hypothesis[11], and it assumes that the data contains correct and abnormal data. The correct data are recorded as inliers, and abnormal data are recorded as outliers. At the same time, RANSAC also assumes that given a set of correct data, there are methods that can calculate model parameters that conform to these data. The algorithm flow is as follows:

- Randomly select the minimum number of points required to determine the model parameters.
- Solve model parameters.
- Calculate whether the distance error of all points relative to the model meets the predefined distance threshold ε .
- If the proportion of the number of interior points in all points exceeds the predefined threshold τ , use all the re-estimated model parameters that meet the error threshold and terminate.
- Otherwise, repeat the process 1)-4) (maximum number of iterations N)

The key is that the number of iterations N should be selected high enough to ensure that the probability that a set of random samples does not contain outliers is p (usually set to 0.99).Set u as the probability that any point is an interior point, then u is the number of interior points in the data/the total number of data center points, then the probability that any m points are interior cluster points is u^m .Therefore, the probability that at least one of the m points we selected is not an inner group point is $1-u^m$; Therefore, if we repeat N times in a row, we can't have the probability that p_e is $(1-u^m)^N$ for all points in the inner group, so the number of iterations N at least m points. Therefore, when u remains unchanged, we want to make p_e as small as possible, and the larger m is, the larger N needs to be. Then the maximum number of iterations N is defined as:

$$N = \frac{\log(1-p)}{\log(1-u^m)}; p_e = 1-p = (1-u^m)^N \tag{3}$$

3. Computation Methods

We proposed that the luggage measurement algorithm mainly includes data preprocessing, point cloud data processing, and luggage attitude information calculation. The following will introduce the details of the algorithm implementation part by part.

3.1. Image Preprocessing

a) Image data acquisition: We use the binocular structured light camera to obtain the color and depth images. Under normal circumstances, the binocular structured light camera integrates ASIC for image feature matching. Although the hardware cost is slightly higher, the processing speed is faster, and the camera supports a high frame rate and high resolution. When the accuracy of the collected data is satisfied, the measurement algorithm does not require a complicated design.

b) Image data to point cloud data: Firstly, cut off the irrelevant image area of the obtained depth image and then perform the point cloud conversion, in which the points whose distance value does not meet the measurement range are filtered out during the conversion. Set the point cloud attribute to limit the effective point cloud range, filter the points, keep the points in the range, and exclude the influence of the surrounding irrelevant point cloud. This operation essentially converts the image coordinate system data into the data in the world coordinate system, and the constraint condition of the transformation is the internal camera parameters.

c) Voxel filtering: The voxel filter can achieve down-sampling without destroying the geometric structure of the point cloud itself, but it will move the position of the point. The principle is first to calculate a cube that can wrap the point cloud according to the input point cloud and then divide the giant cube into different small cubes according to the set resolution. For the points in each small cube, calculate their centroid, and use the centroid coordinates to approximate several points in the cube. This operation can significantly reduce the computational complexity of point cloud processing.

d) Statistical filtering: Statistical filtering is a method based on a statistical analysis of the distance distribution in the neighborhood of a point, considering the average distance from each point to each point in its neighborhood. The principle of filtering is to perform statistical analysis on the neighborhood of each point and calculate the average distance to all nearby points. They are assuming that the result obtained is a Gaussian distribution whose shape is determined by the mean and standard deviation. Furthermore, the points whose average distance is outside the standard range (defined by the global distance mean and variance) can be considered outliers and obtained from the data in the removal.

3.2. Point Cloud Data Preprocessing

This step is the core part of the algorithm. First, the filtered point cloud data is segmented to extract the top surface equation of the luggage. Then point cloud projection is performed. According to the data on the projection plane, the convex hull characterization is used to effectively express the length, width, and area of the luggage

a) Point cloud data segmentation: We use the RANSAC method to fit and estimate the top surface of the luggage on the filtered point cloud data and express the top surface through the obtained plane equation, as shown in (4). Theoretically, the preset conveyor belt plane is horizontal, and the thickness of the luggage can be calculated directly by making a difference. In order to ensure the accuracy of the luggage height data, we randomly select several key points on the top surface of the luggage and calculate the distance between the top surface point and the intersection of the conveyor belt along the average direction of the top surface the luggage.

$$\begin{cases} a_0 x + b_0 y + c_0 z + d_0 = 0 \\ a_p x + b_p y + c_p z + d_p = 0 \end{cases} \tag{4}$$

Among them, a_0, b_0, c_0 and d_0 are the plane equation parameter of the conveyor belt, and a_p, b_p, c_p and d_p are the top surface equation parameter of the luggage fitting.

b) Point cloud projection: According to the top surface equation and conveyor belt plane equation obtained, we project the point cloud data of the top surface onto the conveyor belt plane. This operation can simplify the three-dimensional image processing problem to the two-dimensional image processing problem, significantly reducing the amount of calculation.

c) Convex hull contour representation: After projecting the point cloud data onto the conveyor belt plane, a two-dimensional image can be obtained. Since we calculate the length and width of the luggage on the two-dimensional image, we then use the convex hull algorithm[12] to find the convex hull of the plane projection point. The Fig. 3 shows that the white points and magenta points are the point cloud obtained after preprocessing. The magenta point cloud is the data point participating in the fitting of the top surface of the luggage. The pink point cloud is the result of the projection operation. The cyan point cloud is the key data point of the convex hull detection result.

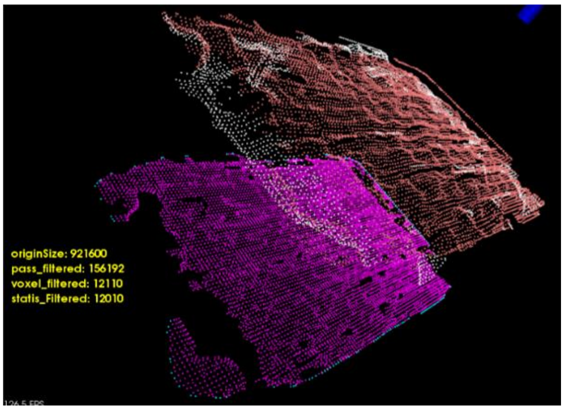


Fig. 3: Visualization of point cloud processing results

3.3. Attitude Information Calculation

For the obtained convex hull point set, calculate the minimum circumscribed rectangle of the convex hull. According to the relevant parameters of the circumscribed rectangle, the maximum length, width, center point coordinates, and skew angle relative to the reference line can be obtained. An object is measured multiple times, and a specific filtering process is performed on the detected information to obtain more accurate and stable results.

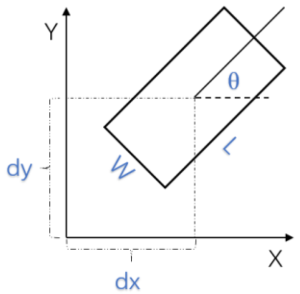


Fig. 4: Luggage output data definition.

As shown in Fig. 4, $\theta \in \left[-\frac{\pi}{2}, \frac{\pi}{2}\right]$ is defined as the angle between the luggage and the conveyor belt; w and l are the length and width of the luggage; d_x and d_y are the distance from the center of the luggage to the center of the camera's field of view, h is the thickness of the luggage, and L is the distance from the camera center The distance value of the conveyor belt plane; the corresponding $d = L - h$ represents the distance from the top surface of the luggage to the center of the camera.

4. Implementation And Experiment

4.1. Experimental Setup

In the experiment, an RGBD camera (Intel RealSense D435) is used as the image sensor, based on the NVIDIA Jetson AGX Xavier computing power board as the hardware platform, Ubuntu 18.04 as the operating system to build the luggage detection system hardware system. The image resolution is defined as 848*480, and the long side corresponds to the direction of movement of the luggage. Based on the binocular parallax model, using C++ as the development language, combined with the OpenCV[13] library and the PCL[14] library, the development of luggage positioning and measurement algorithms, detection of luggage appearing on the conveyor belt, and realization of the size and pose of the luggage object calculate. The camera installation is shown in Fig. 5.

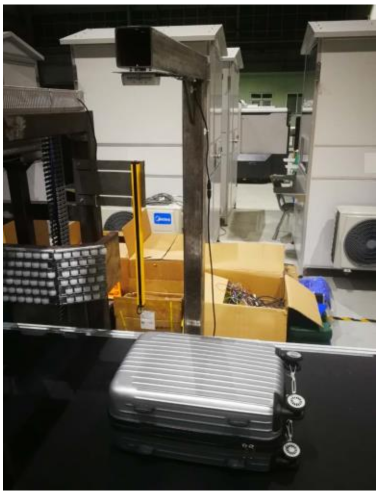


Fig. 5: Schematic diagram of measuring system

Table 1: Static measurement results of luggage

Example	Type	True Value	First	Second	Third	Fourth	Fifth	Sixth	Seventh	Eighth	MAE_{mean}	$MAE_{\max}$
luggage1	Length	0.4600	0.4770	0.4508	0.4490	0.4531	0.4724	0.4674	0.4770	0.4807	1.27	2.07
	Width	0.3400	0.3600	0.3457	0.3314	0.3200	0.3408	0.3367	0.3216	0.3204	1.20	2.00
	Height	0.2300	0.2367	0.2224	0.2323	0.2302	0.2392	0.2325	0.2259	0.2348	0.47	0.92
	Angle	0.00	0.40	1.46	−0.65	−0.07	−0.65	−0.36	−1.09	−0.73	0.68	1.46
	Time	---	0.3381	0.3291	0.3367	0.3391	0.3394	0.3467	0.3523	0.3347	--	---
luggage2	Length	0.5100	0.5018	0.5350	0.5166	0.5309	0.5243	0.5187	0.5105	0.5233	1.22	2.50
	Width	0.3400	0.3172	0.3291	0.3410	0.3291	0.3462	0.3552	0.3167	0.3571	1.34	2.33
	Height	0.2700	0.2744	0.2760	0.2698	0.2802	0.2751	0.2637	0.2723	0.2616	0.54	1.02
	Angle	0.00	−0.10	−0.25	0.18	−1.17	1.42	−0.40	1.06	1.24	0.73	1.43
	Time	---	0.3511	0.3506	0.3439	0.3492	0.3496	0.3521	0.3485	0.3447	---	---
luggage3	Length	0.5900	0.5794	0.5912	0.5646	0.5882	0.5640	0.5652	0.5988	0.5977	1.33	2.60
	Width	0.3900	0.3885	0.4072	0.4098	0.4153	0.4098	0.3814	0.3758	0.3728	1.55	2.53
	Height	0.2600	0.2685	0.2519	0.2594	0.2525	0.2696	0.2598	0.2675	0.2649	0.59	0.96
	Angle	0.00	−0.58	−0.14	0.58	1.61	−0.80	1.68	1.35	−1.13	0.99	1.68
	Time	---	0.4810	0.4698	0.4825	0.4638	0.4921	0.4878	0.4565	0.4612	---	---

Table 2: Dynamic measurement results of luggage

Example	Type	True Value	First	Second	Third	Fourth	Fifth	Sixth	Seventh	Eighth	MAE_{mean}	$MAE_{\max}$
luggage1	Length	0.4600	0.4445	0.4265	0.5090	0.4815	0.4325	0.4827	0.4540	0.5066	2.78	4.90
	Width	0.3400	0.3847	0.3076	0.3762	0.3019	0.3676	0.3838	0.3076	0.3410	3.20	4.47
	Height	0.2300	0.2387	0.2390	0.2245	0.2344	0.2390	0.2312	0.2288	0.2187	0.63	1.13
	Angle	0.00	−0.35	1.13	−2.46	−1.64	−2.00	1.74	1.49	0.05	1.36	2.47
	Time	---	0.3507	0.3524	0.3156	0.3415	0.3449	0.3225	0.3558	0.3317	---	---
luggage2	Length	0.5100	0.4793	0.5367	0.4764	0.5595	0.4655	0.4803	0.4833	0.5140	3.07	4.95
	Width	0.3400	0.3699	0.3090	0.3795	0.3069	0.3475	0.2930	0.3571	0.3539	2.74	4.70
	Height	0.2700	0.2787	0.2635	0.2812	0.2577	0.2660	0.2747	0.2591	0.2812	0.87	1.23
	Angle	0.00	−0.15	−1.90	−1.33	−2.15	1.07	0.41	−1.07	0.20	1.04	2.16
	Time	---	0.3317	0.3388	0.3637	0.3347	0.3418	0.3305	0.3311	0.3613	---	---
luggage3	Length	0.5900	0.5545	0.5431	0.6014	0.6289	0.5602	0.5854	0.5774	0.5614	2.60	4.69
	Width	0.3900	0.4392	0.4327	0.3644	0.4285	0.4242	0.3451	0.3654	0.3782	3.39	4.92
	Height	0.2600	0.2624	0.2603	0.2534	0.2718	0.2715	0.2705	0.2705	0.2610	0.68	1.18
	Angle	0.00	2.49	−0.11	1.10	−0.77	−2.43	2.43	1.88	2.21	1.68	2.49
	Time	---	0.4522	0.4926	0.4848	0.4607	0.4763	0.4572	0.4395	0.4345	---	---

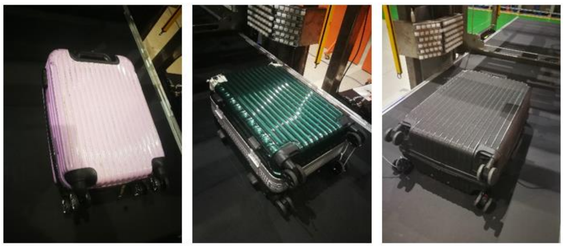
4.2. Experimental Results

Under normal indoor conditions, we measure the size of multiple luggage on-site, as shown in Fig. 6, to test a sample of luggage, (a.luggage1-L1, b.luggage2-L2; c.uggage3-L3). We measure the luggage under static and dynamic conditions, and the obtained data are shown in Table 1 and Table 2(length, width, height unit metric, angle unit degree; time unit sec). There are two evaluation indicators, the average absolute error(MAE_{mean} define as (5)), and the maximum absolute error($MAE_{\max}$ define as (6)). The results show that the measured value is consistent with the actual value, the static measurement MAE_{mean} of length and width is less than 2 cm, the $MAE_{\max}$ is less than 3 cm; the dynamic measurement MAE_{mean} of length and width is less than 3 cm, and the $MAE_{\max}$ is less than 5 cm.

$$MAE_{mean}(X, y) = \frac{1}{m}\sum_{i=1}^{m}|x_i - y| \tag{5}$$

$$MAE_{\max}(X, y) = \max(|X - y|) \tag{6}$$

It is vital to pay special attention to the fact that the error of the length and width dimensions is much larger than the error of the height dimension. Because the length and width of baggage introduce errors in the measurement process, the measurement accuracy is slightly low. The cause of this error will be analyzed in detail in the following chapters. The shape of the luggage and the movement state have a great relationship.



(a) (b) (c)

Fig. 6: Schematic diagram of test luggages

At the same time, we also fairly compared other algorithms in the measurement of luggage. We tested Gao[1], Zhang[3], Chelishchev[4] and our algorithm on L1 under static conditions. From Table 3, we can clearly see that our method outperforms the Gao and Zhang algorithms in both measurement accuracy and speed, and also far outperforms the Chelishchev algorithm in terms of speed and height. It fully demonstrates the effectiveness of our measurement method. It is important to note that we do not yet have an algorithm that is highly adapted for comparison. Meanwhile, our camera would have more advantages. But it can still explain the superiority of our algorithm to a certain extent.

Table 3: Compare with other algorithms

Type	True	Gao	Zhang	Chelishchev	Ours
Length	0.4600	0.4324	0.4889	0.4665	**0.4701**
Width	0.3400	0.3146	0.3256	0.3475	**0.3565**
Height	0.2300	0.2098	0.2424	0.2198	**0.2387**
Time	--	1.3507	2.0241	2.8215	**0.3491**

After further analysis of the results, it is found that the calculation time is positively correlated with the size of the luggage by carrying out the measurement experiment with different sizes of luggage. The larger the luggage, the longer the algorithm running time. Then the algorithm can be migrated to e-commerce logistics to detect the size of express delivery. After adaptation, it can meet the needs of real-time detection.

4.3. Discussion

After analyzing the experimental results, it is found that there is still a certain gap between the obtained results and the actual luggage size and parameters. After the analysis, the possible introduction of errors mainly comes from:

- Most of the materials of the tested luggage are plastic, which is inevitable to have certain deformation. Moreover, the edges and corners of the luggage are mostly arc chamfers, which will affect the accuracy of the measuring point.

- The luggage is slightly bumpy during the movement, which causes the top surface to shake.
- The deviation of each reference plane leads to the measurement deviation.
- The stability of the image data source itself.
- The insufficiency of the algorithm, Due to the unevenness of the top surface of the luggage, the algorithm can fit the upper surface of the luggage to introduce a deviation.

5. Conclusion

This paper proposes a system scheme for the visual measurement of luggage. The system obtains scene data from binocular cameras and effectively combines point cloud processing and image processing methods to extract relevant and adequate information. Compared with other methods, it measures the baggage efficiently and greatly reduces the amount of calculation. This shows that the system meets the requirements for efficient measurement of luggage information.

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