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Research on Corners Detection of Hazardous Chemicals Stackings and Distance Measurement Algorithm Based on Piecewise Straight-Line Fitting

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Abstract. The storage of hazardous chemicals is related to the safety of people and city. At present, a method that hazardous chemicals are stored in the warehouses of the bungalows is adopted widely. The monitoring of all safety status are key problems, especially for the safety distance measurement of "five-distance". In this thesis, aiming at the problems of effective corners extraction in binocular visual distance measurement, a united algorithm that based on Shi-Tomasi corners detection and improved Piecewise straight-line fitting is presented, in which a method of removing noise corners by using K-Nearest Neighbors algorithm is used and effective corners are intersections of fitting line. The experimental results show that the method can effectively remove false corners and recover the missing effective corners. The accuracy of corner extraction is more than 80%, and the distance measurement error is less than 2 cm.

Keywords: corners extraction, hazardous chemicals stackings, removing noise corners in k-nearest neighbors, Shi-Tomasi detection, straight-line fitting

1 Introduction

The preparation of manuscripts which are to be reproduced by photo-offset requires special care. Papers submitted in a technically unsuitable form will be returned for retyping, or canceled if the volume cannot otherwise be finished on time. Nowadays, with the development of society, the demand of warehouse of hazardous chemicals is increasing. There are numerous hidden dangers in the storage of hazardous chemicals because of the characteristics of hazardous chemicals, such as flammable, explosive and corrosive features. In light of these problems, there is an urgent need for an internal safety monitoring and warning system for safe storage of hazardous chemicals [1-2]. The Machine Vision is a rapidly developing branch of artificial intelligence and the applications of three-dimensional measurement of binocular visions are very extensive and Wang Hongwei et al. proposed a distance measurement system for traffic lights based on binocular vision [3] and Li et al. designed and implemented a vehicle distance measurement system using binocular vision [4]. Quan Yan ming et al. realized the measurement of workpiece size [5]. But the Stacking safe "5-distance" including stacking distance, wall distance, column spacing, lamp spacing and beam spacing is an important factor in the safe storage of hazardous chemicals. Aiming at this issue, a hazardous stacking distance measurement and restoration system based on binocular vision [6] was designed in which effective corners detection is key information for measuring distance.

For the corners issue, some related scholars have devised a variety of detection methods. For example, in 2006, Rosten and Drummond [7] proposed a corner detection algorithm based on features from

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accelerated segment test (FAST). This algorithm is famous for its fast speed and is suitable for image processing with high real-time requirements. However, FAST algorithm can only detect single type of corner, and missing corners will occur [8]. And Awrangjeb and Lu [9] proposed a multi-chordal corner detection algorithm based on chord-point distance accumulation (CPDA), in which does not utilize any first-order and second-order derivatives, so it can lead to better noise robustness. And Harris operator has an advantage of ideal corners extraction but some difficulties such as fixed dimensions and difficult to set thresholds still exist [10]. And Zhao and Yang [11] proposed an algorithm combining wavelet transform with Shi-Tomasi corner detection, which can reduce the computation amount and remove false corners.

The hazardous chemicals stacking are usually consisted of standard box bodies including cuboids and cubes and have basic features of corners and lines. Thus, the hazardous chemicals Stacking corners detection and the research of distance measurement system all based on piecewise straight-line fitting are proposed, in which the feedback process can be conducted by using intersections obtained after piecewise straight-line fitting to corners obtained after Shi-Tomasi detection and denoising in order to extract the effective corners for measuring distance. This method can remove the false corners affecting distance measuring, find the missing effective corners, effectively remove the noise corners, and have an important research significance for subsequent stereo matching, distance measurement and 3D restoration.

2 Algorithmic Process

Size measurement of hazardous chemicals warehouse stacking needs to detect the location of box vertex, which cannot be achieved by general corner algorithm. So, a corner detection and distance measurement system based on straight-line fitting is proposed. As shown in Fig. 1, Firstly, Shi-Tomasi operator is used to detect the corners of the captured images, and then K Nearest Neighbor is used to denoise the image. And only the corners on the edge of the cargo are preserved. Then piecewise straight-line fitting process is conducted by using these corners. In the process of piecewise straight-line fitting, the segmentation is carried out according to the slope range of the cargo box body edge. At last, the intersections and corners obtained after fitting can be used to determine the effective corners needed for distance measurement.

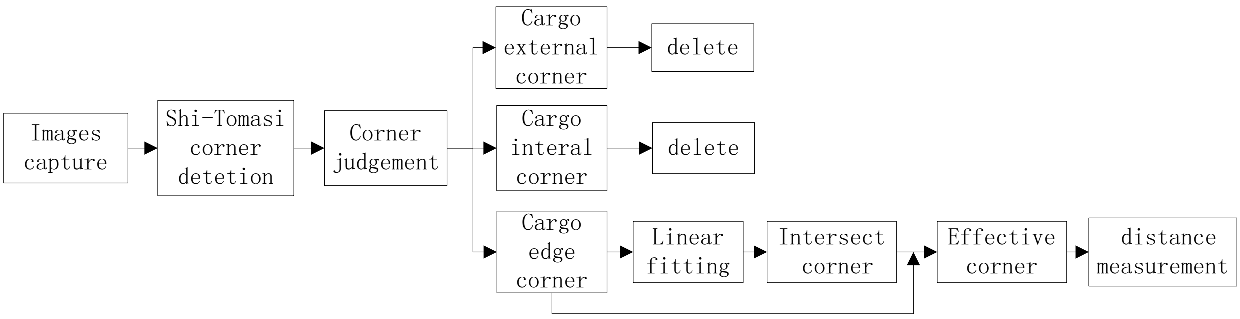


Fig. 1. Flow chart of system

3 Shi-Tomasi Corner Detection Algorithm

Only when the number of corners increases in the coarse detection process, the result of line fitting will be more accurate. The basic idea of Shi-Tomasi algorithm is to slide a fixed window in any direction on an image, and compare the gray-scale variation of the pixels in the window before and after sliding. At corners position, the first-order derivative of gray-scale image is at local maximum value, and the gray-scale of image changes in all directions. Derivatives are usually sensitive to noise, so the filters must be used to improve the performance of corner detector related to noise. Here, median filtering is used for denoising.

Set the value $I(x, y)$ for gray-scale image at point (x, y), and build a $n \times n$ window using this point as a center. The produced gray-scale variation after the process of window translational motion $[u,v]$ is presented in following equation 1.

$$E(u,v)=\sum_{x,y} w(x,y)\left[I(x+u,y+v)-I(x,y)\right]^2 \tag{1}$$

The $w(x,y)$ is a Window function which can be expressed using Binary Gaussian function. $[u,v]$ is an offset of the window and dimension of the windows can determine how many places there are [12].

The Taylor expansion is used in the expression of $E(u,v)$：

$$\begin{aligned} E(u,v) &= \sum\left[I(x+u,y+v)-I(x,y)\right]^2 \\ &= (u,v)\sum_{x,y} w(x,y)\begin{bmatrix} I_x^2 & I_xI_y \\ I_xI_y & I_y^2 \end{bmatrix}\begin{pmatrix} u \\ v \end{pmatrix} \end{aligned} \tag{2}$$

Among them, I_x and I_y are partial derivatives in x and y directions in gray-scale images, and the matrix here is covariance matrix which can be expressed using M：

$$M=\sum_{x,y} w(x,y)\begin{bmatrix} I_x^2 & I_xI_y \\ I_xI_y & I_y^2 \end{bmatrix} \tag{3}$$

At last, the final equation can be got:

$$E(u,v)=\left[u,v\right]M\begin{bmatrix} u \\ v \end{bmatrix} \tag{4}$$

The Eigenvalue Solving process is conducting through the matrix M and the smaller eigenvalue between two eigenvalues is larger than minimum threshold, and then, the stronger corner can be obtained.

4 The Coarse Extraction of Corners in K-Nearest Neighbor

There will be some false corners in all the corners obtained by Shi-Tomasi algorithm and these false corners, such as Fig. 2(a) and Fig. 2(b) in Fig. 2, called noise corners which can cause adverse influence to line fitting process, should be removed. Based on the binary image of the safety condition of the full stacking of hazardous chemicals warehouse shown in Fig. 2(c) and Fig. 2(d), then the K-nearest neighbor corners rough extraction process is conducted using corners detected by Shi-Tomasi algorithm.

(a) Detected original image | (b) Detected corners image | (c) Stacking original image | (d) Standard binary image

Fig. 2. The schematic images

All corners detected by Shi-Tomasi algorithm are classified into three categories, i.e. inside, outside and on the edge of the cargo. And Fig. 3 is the schematic of corners. In it, ① presents the outer corner of the cargo, ②④ present the inner corners of the cargo, ⑤ presents the overlapping part and belongs to the inner corner of the cargo, and ③⑥ present the corners on the edge of cargo. The solid line part in fowling Fig. 3 is the targeted cargo, that is, the cargo that needs to be measured. So, the piecewise straight-line fitting should be done by using edge corners of the targeted cargo. And in Fig. 3, ① to ⑤ are noise corners and ⑥ is the effective corner.

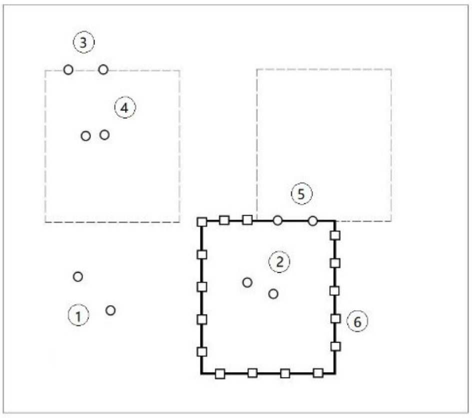


Fig. 3. The distribution of corners

Fig. 3 shows that the noise corners account for about 40% of the total corners, but about 90% of the noise corners are distributed in an inside and outside position of the binary image which is in a standard of full stacking. The black pixel value is 0, the white pixel value is 1, and the noise corners pixel value is 0 or 1, which can remove the noise corners better.

According to the information above, the pixel information value in neighbor of every corner can be obtained to judge the position of corners. And the noise corners should be deleted and the corners on the edge should be preserved. As shown in Fig. 4, set the neighborhood to 9×9, then (x, y) is position of corner.

…	…	…	…	…
…	(x-1,y+1)	(x,y+1)	(x+1,y+1)	…
…	(x-1,y)	(x,y)	(x+1,y)	…
…	(x-1,y-1)	(x,y-1)	(x+1,y-1)	…
…	…	…	…	…

Fig. 4. 9×9 Neighborhood graph

The average value of corners position in the standard binary image and surrounding 81 pixels values should be found using equations below：

$$\begin{cases} (\sum_{i=1}^{n} I_{i(x,y)})/n \in [0,0.2) \\ (\sum_{i=1}^{n} I_{i(x,y)})/n \in [0.2,0.8] \\ (\sum_{i=1}^{n} I_{i(x,y)})/n \in (0.8,1] \end{cases} \quad (5)$$

When the average pixel value is between 0-0.2 and 0.8-1, the corners are located inside and outside the cargo, such as ①②④⑤ shown in Fig. 4. The corners in these positions will be deleted. The corner in the position ③, that is the noise corner, will be preserved, but it will not be detected in the subsequent operation of piecewise straight-line fitting, because the amount of this kind of noise corner is few.

4.1 Piecewise Straight-Line Fitting

The example image of corner underwent denoising is shown in Fig. 5, and Fig. 5(b) is a corner image, and Fig. 5(c) is a corner schematic image. It can be seen that corners redundancy (yellow) and missing corners (green) will occur in distance measurement process. Then, it can be found that all the effective corners are some parts of intersections in straight lines. Therefore, a piecewise straight-line fitting operation is adopted here to extract the intersections.

(a) Before Denoising (b) After denoising (c) Schematic image of corners

Fig. 5. The sample images

For general straight-line fitting, segmentation means conducting a linear fitting from one segment to another according to the different slopes from the starting corner to ending corner. However, for cargoes in hazardous chemicals warehouse, they are closed set of points and the general piecewise straight-line fitting cannot meet this requirement. Therefore, according to their characteristics, the straight-line fitting is carried out before grouping corners in a certain range.

The flow chart of corners grouping is shown in Fig. 6. Firstly, three kinds of large containers are established to store 3 types of lines respectively, namely length, width and height of the stacking: K1, K2 and K3. And each large container contains several small containers， that is K1 (k1, k2, ...). Then, obtain the corners cyclically and look for other new corners in the 8×8 neighborhood of a corner, and then calculate the slopes using new corner and known corner. And then judge the type of lines formed by two corners and store these corners in the corresponding container at last.

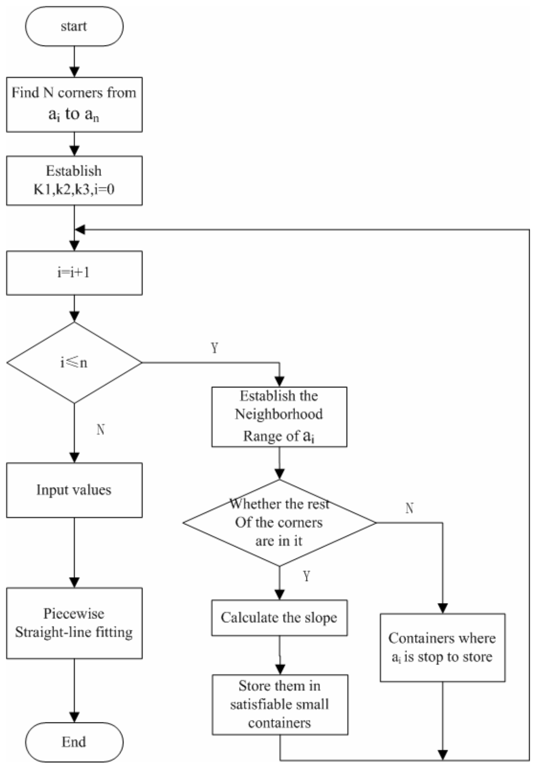


Fig. 6. The process of piecewise straight-line fitting

When the slope of the detected corner meets one type of length, width or height requirement, for instance, the slope of the detected corner meets the slope range of height, but the new corner does not exist in the corner range, then a new small container will be opened in this type, proving that next, the second height will meet this slope. Finally, all small containers conduct the line fitting process. After pretreatment corners separation, the corners on the stacking will be divided into many types and different kinds of corners will not be fitted, which can greatly reduce the complexity of fitting and improve the accuracy of straight-line fitting.

The least square method is adopted to conduct a straight-line fitting for corners which finished classification process. According to the given corner (x_i, y_i), the approximate curve $y = \varphi(x)$, can be obtained. If the first order polynomial of a straight-line is set as $y = kx + b$, the deviation, which is $e_i = y_i - \varphi(x_i)$, $(i = 1,2,3...n)$, can be obtained. In order to consider the overall error, quadratic sum should be used. The reason why quadratic sum is to take into account is that the direct add of the positive and negative of error values can cancel each other [13], so the error is recorded as the sum of squared deviations.

$$e^2 = \sum_{i=1}^{n} (y_i - (kx_i + b))^2 \tag{6}$$

Then, find the minimum value of sum of squared deviations using method that take partial derivatives to every variable and the minimum value can be obtained when the value of partial derivative is 0.

$$\frac{\partial e}{\partial a} = \sum_{i=1}^{n} 2(y_i - (kx_i + b)(-x_i) = 0 \tag{7}$$

$$\frac{\partial e}{\partial b} = \sum_{i=1}^{n} 2(y_i - (kx_i + b)(-1) = 0 \tag{8}$$

At last, the value of k and b can be found and the linear equations after fitting operation can be found. And the matrix is presented as follow:

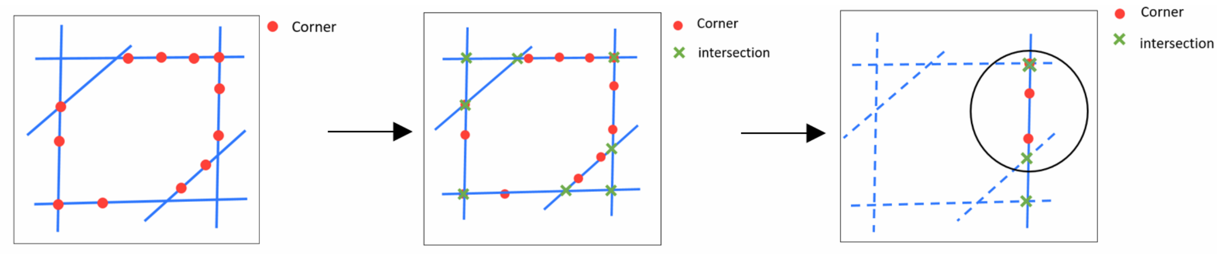
$$\begin{pmatrix} \sum_{i=1}^{n} x_i^2 & \sum_{i=1}^{n} x_i \\ \sum_{i=1}^{n} x_i & n \end{pmatrix} \begin{pmatrix} k \\ b \end{pmatrix} = \begin{pmatrix} \sum_{i=1}^{n} y_i x_i \\ \sum_{i=1}^{n} y_i \end{pmatrix} \tag{9}$$

In order to obtain intersections easily, the linear equations above should be preserved.

4.1 The Extraction of Effective Corners

The precise intersections can be obtained after the operation of piecewise straight-line fitting. As shown in Fig. 7, Fig. 7(a) is edge corners image mentioned above, it can be seen that the effective corners are not completely extracted, and there appears corners redundancy. And in Fig. 7(b), the number of intersections increases based on corners. It can be seen that the effective corners are extracted completely, but the redundant corners will cause interference. However, the detected positions, which are both the corners and intersections, must be the effective corners and should be remained.

Next, any analysis expression in Fig. 7(b) is operated. As shown in Fig. 7(c), a corner (not an intersection) is selected as the center of the circle and i (i > 0) as the radius of the circle. When two reverse intersections are contained in the circle, the circle stops expanding and the two intersections must be the effective corners. Thus, the six effective corners needed for a cargo are extracted completely. And next, matching and distance measurement should be done.

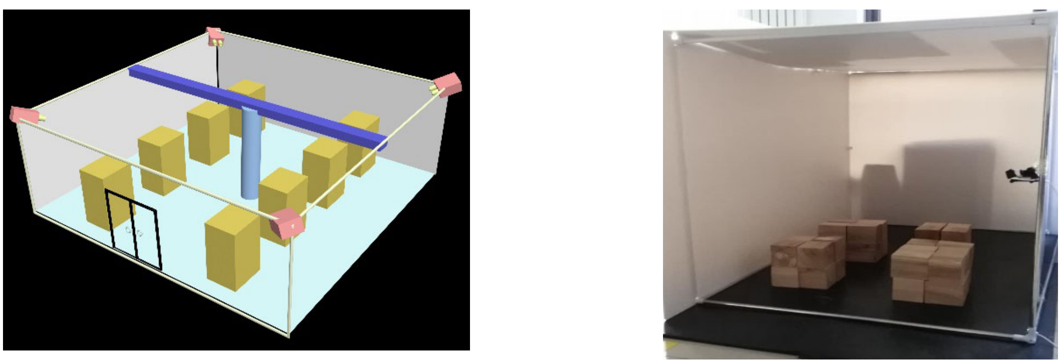


(a) Corners (b) Intersections and corners (c) Effective corners

Fig. 7. Schematic diagram of corner index

5 Experimental Results and Analysis

In a laboratory environment, a 2*1*1m simulated warehouse environment was built using a CMOS binocular camera of 2 megapixels, same 100*100*100mm boxes and 80*80*80mm boxes. And 100 groups of images with different stacking combinations were processed. The simulated warehouse is shown in Fig. 8.



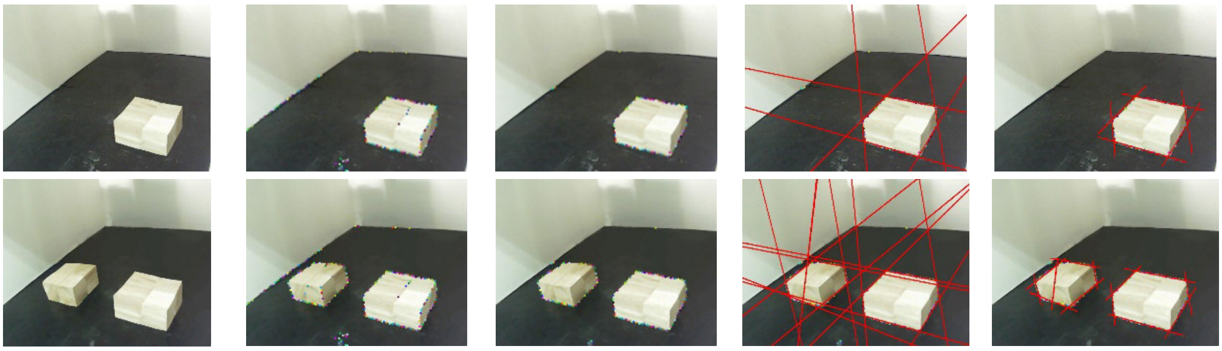
(a) Schematic image of warehouse (b) Warehouse example

Fig. 8. Image of simulated warehouse

5.1 Corners Evaluation

In the experimental environment, the pixel size of captured image is 640*480 as shown in Fig. 9(a), and Fig. 9(b) is the image of corner detection, and Fig. 9(c) is the image of removing noise corners using K Nearest Neighbor method, and Fig. 9(d) is the image representing straight-line fitting result, from which it can be seen that lines fit the edge basically and intersections and box position are basically in the same position, and Fig. 9(e) is the image of changing the lines into line segments according to the position range of the starting corner and the ending corner to avoid false intersections obtained by lines penetrate cargoes in other locations.

The algorithm proposed in this thesis is compared with Shi-Tomasi corner detection algorithm, sub-pixel corner detection algorithm and Harris corner detection algorithm. The CPU of the test computer is Intel CORE i7 7500U, the memory is 16GB, the operating system is Windows 10 and the programming software is Opencv+ Visual Studio2013. After a large number of experiments and statistical analysis, 100 groups of images in this experiment are randomly selected for conducting contrast experiments and the results of evaluation are as follows [14].



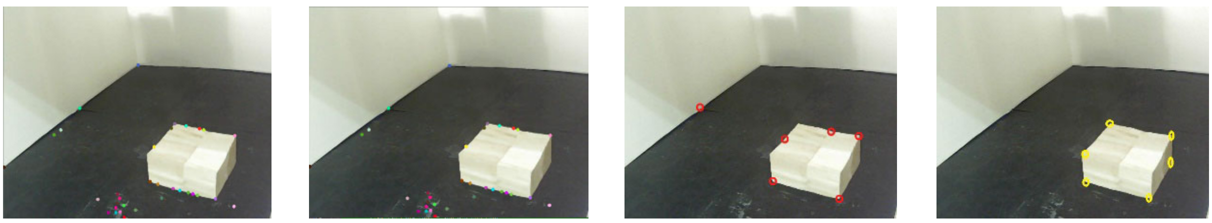
(a) Original image (b) Shi-Tomasi (c) K Nearest Neighbor (d) Straight-line fitting (e) Intercepting line segments

Fig. 9. The example of results

The average value of 100 groups of images are shown in Table 1. The rate of error corners is equal to the number of error corners divided by the number of corners to be detected; The rate of missing corners is equal to the number of missing corners divided by the number of corners to be detected; and the rate of correct corners is equal to the number correct corners divided by the number of corners to be detected. It can be seen that the algorithm mentioned in this thesis reduces most of the noise. And after an operation of straight-line fitting, the lines obtained intersect to get corners to make up missing corners. And the average rate of correct corners is more than 80%, and this rate can reach 100% when the effective corners are less. Parts of examples are shown below.

Table 1. Results of different algorithms

Algorithm	False corners rate/%	Missing corners rate/%	Right corners rate/%	Time/ms
Shi-Tomasi	90.87	45.19	54.81	568
Subpixel level	87.37	45.18	54.82	217
Harris	43.23	67.72	32.28	270
article	36.52	19.44	80.56	153

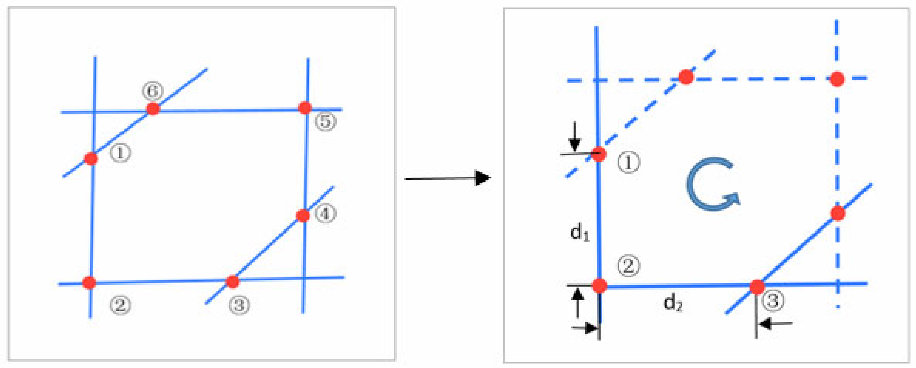


(a) Shi-Tomasi (b) Subpixel level (c) Harris (d) article

Fig. 10. Results of corner detection

5.2 Distance Measurement

Take a cargo stacking as an example to conduct a distance measurement. From Fig. 11(a), it can be seen that ① to ⑥ are the effective corners for distance measurement, and the distance between the corners are the length, width and length of the cargo. Firstly, ① is detected, and then detect another intersection, that must be ②, on the line where ① is. d1 and d2 and other distance values can be measured.



(a) (b)

Fig. 11. Distance measurement

Here, the Zhang calibration and SURF stereo matching algorithm are adopted. The distance measurement results in Fig. 11 are shown in Table 2. The error range is basically within 2 cm and the factors affecting the measurement results include the error of camera calibration parameters, the error of stereo matching, the deviation of corners and so on.

Table 2. Measuring result

Distance	The actual size /cm	Size detection /cm
①-②	10	11.53
②-③	20	18.96
③-④	20	20.86
④-⑤	10	15.36
⑤-⑥	20	21.60
⑥-①	20	19.53

6 Conclusion and Future Work

Safety storage distance measurement in the warehouse based on binocular visual distance measurement is a non-contact measurement, which can provide technical supervision for hidden dangers in hazardous chemicals warehouses. The Shi-Tomasi corners detection and a united algorithm of improved piecewise straight-line fitting improves the extraction accuracy of effective corners in distance measurement, meanwhile, a further accuracy improvement of algorithm is achieved by combining K-Nearest Neighbor denoising and feedback judgment of lines intersections. The experimental results show that the accuracy of corner detection of this method is more than 80%, and the distance error is less than 2 cm. The next step is to study the corners on the edges in the shaded part, so as to reduce the shaded loss of the effective corners.

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