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A STABLE DECODING ALGORITHM BASED ON CIRCULAR CODED TARGET

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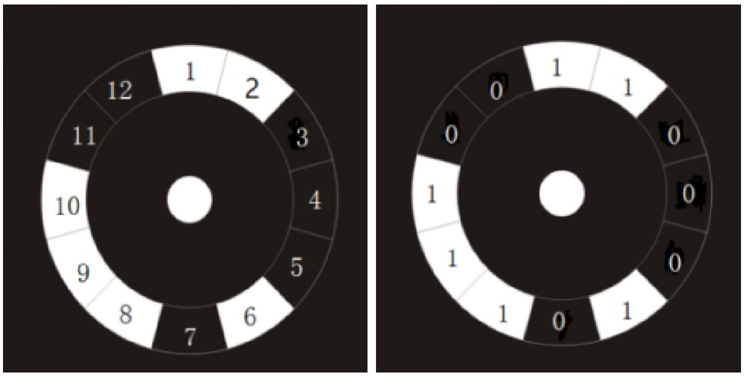
Abstract. *In order to solve the problem of low accuracy and efficiency in decoding the circular coded targets in close range photogrammetry, an efficient extraction and robust recognition algorithm for circular coded targets is proposed. In this algorithm, the noise and interference are filtered by the contour perimeter and the ratio of long axis and short axis after the least square ellipse fitting of the contour. In order to locate the coded targets accurately, the gray squared weighted centroid method is taken to locate the centroid of coded targets. Finally, a new algorithm based on the decoding endpoint is proposed to decode the coded targets. Experimental results show that the average recognition accuracy can reach 99.2% when the angle between the camera optical axis and the normal of coded target is less than 60°. Furthermore, the recognition accuracy rate can still reach 93% when the angle is 70°. When applied to the images containing complicated background information, the global recognition accuracy, false recognition rates and the average elapsed time are 97.2%, 1.11% and 2.47s respectively, which validates the optimality of its comprehensive performance compared with other existing recognition algorithms.*
Keywords: Coded target detection, Coded target recognition, Edge detection, Decoding endpoint, Decode

1. **Introduction.** With the continuous development of computer vision, a series of research work has been done on the difficulties of camera calibration and 3D data stitching in this field. In order to reduce the complexity of the problem, a coded target with unique identity information is introduced. Therefore, it is very important to study the design, extraction and accurate identification of circular coded targets [1].

At present, a lot of research work has been done on the detection and recognition of the circular coded targets. R. Chen et al. used the gray gradient to get the central angles of each coded section, but it increased the computational complexity, ran slowly and had low recognition rate under fuzzy conditions [2]. The recognition method proposed by L. Jin et al. in camera calibration [3-5] has a high requirement on the shooting angle and the environment, and is not suitable for the ordinary close range photogrammetry; a presented ellipse-incircle-division algorithm based on the invariance to the affine transformation of circular coded targets was proposed by Z. X. Xie et al. [1], this method can easily lead to uneven segmentation, thus affecting the decoding results; L. Song et al. [6] proposed an affine transformation invariance based on the coded targets, the imaging ellipse is transformed into a straight line and a unit circle by means of coordinate transformation, to achieve recognition of circular coded targets. The algorithm has large computation and low recognition efficiency.

In order to realize the precise positioning and decoding of the circular coded targets, this paper presents a coding targets recognition algorithm based on decoding endpoints. In this paper, the maximum intraclass variance method (OTSU) [7] is used to binarize the image firstly, and then the image is extracted by the Canny operator. The noise and non-circular mark points are filtered according to the ratio of the circumference of the contour to the length of the long axis after the least squares elliptic fitting of the contour. And then use the gray-weighted square centroid method to accurately locate the coding mark points. Finally, the coded tag point is decoded by finding the decoding endpoint. The experimental results show that the proposed algorithm can reduce the influence of the projection angle and the image noise, and realize the accurate location and accurate identification of the coded targets. Figure 1 shows the design of the circular coded targets.



(a) (b)

FIGURE 1. Design diagram of the coded target

In this paper, the first section introduces the development history and research status of the circular coded target, and a circular coded target recognition algorithm based on decoding endpoints is proposed. The second section introduces the algorithms used to detect and locate the circular coded targets. The third section introduces the recognition algorithm of the circular coded targets based on decoding endpoints. The fourth section analyzes the experimental results and verifies the feasibility of the algorithm. This article is summarized in Section 5.

2. Detection and Location of the Circular Coded Targets.

2.1. Circular target detection algorithm. In order to segment the coded target from the image, it needs to use a certain restrictive method. The contour perimeter is used to remove noise, then the least squares ellipse fitting was used to fit the contour, and the non-circular targets were excluded by the ratio of long axis and short axis after fitting. After extraction contour by Canny algorithm, calculate the perimeter of the contour, set the appropriate contour perimeter threshold, delete the contour which does not meet the threshold condition, and then do the least squares ellipse fitting for the contour which satisfies the threshold condition.

2.1.1. *The least squares ellipse fitting.* In the actual measurement, because of the angle of the shooting, most of the circular targets are ellipses, in order to obtain the long and short axes of it, least square ellipse fitting is necessary. For any position of the ellipse, the equation is denoted as follows, among which, (x, y) is the point on the ellipse:

$$\begin{cases} f(x,y) = x^2 + Axy + By^2 + Cx + Dy + E = 0 \\ A^2 - AB < 0 \end{cases} \tag{1}$$

Then the five basic parameters of the ellipse are calculated, among which, x_c, y_c as the center point coordinates, a, b for the long axis and short axis of the ellipse, θ for the attitude angle.

$$x_c = \frac{AD - 2BC}{4B - A^2} \tag{2}$$

$$y_c = \frac{AC - 2D}{4B - A^2} \tag{3}$$

$$\theta = \arctan \sqrt{\frac{Bb^2 - a^2}{b^2 - Ba^2}} \tag{4}$$

$$a = \sqrt{\frac{2\left(BC^2 + D^2 - ACD - 4BE + A^2E\right)}{\left(4B - A^2\right)\left(B + 1 - \sqrt{A^2 + (B-1)^2}\right)}} \tag{5}$$

$$b = \sqrt{\frac{2\left(BC^2 + D^2 - ACD - 4BE + A^2E\right)}{\left(4B - A^2\right)\left(B + 1 + \sqrt{A^2 + (B-1)^2}\right)}} \tag{6}$$

In the same image, the distortion or scaling of the image is the same, that is to say, all the circular markers pasted on the object are similar in the same image, and all the ratio of long axes and short axes of the circular markers is the same. According to this special nature, set a threshold M, by Formulas (5) and (6), calculate the long axis and short axis of each ellipse, if the axial ratio of the ellipse satisfies Formula (7):

$$\frac{a}{b} \leq M \tag{7}$$

Considered that the ellipse is fitted by the contour pixels of the circular markers, reserve it, and if not satisfying (7), eliminate it.

2.2. **Central location of the circular targets.** The premise of the decoding of the circular coded targets is to extract the center of the circular markers accurately. This paper uses the gray squared weighted centroid method to locate center coordinates.

Set the image gray level as $f(x, y)$, among which, $x = 1, \ldots, m$, $y = 1, \ldots, n$, and the thresholding process is described as follows:

$$F(x, y) = \begin{cases} f(x, y), & f(x, y) \geq T \\ 0, & f(x, y) < T \end{cases} \tag{8}$$

Here, T is represented as a background threshold.

Supposed x_0 and y_0 are the coordinate values of gray square weighted centroid, the gray square weighted centroid formula is expressed as follows:

$$x_0 = \frac{\sum_{x=1}^{m}\sum_{y=1}^{n} F(x, y)^2 x}{\sum_{x=1}^{m}\sum_{y=1}^{n} F(x, y)^2}, \quad y_0 = \frac{\sum_{x=1}^{m}\sum_{y=1}^{n} F(x, y)^2 y}{\sum_{x=1}^{m}\sum_{y=1}^{n} F(x, y)^2} \tag{9}$$

The gray squared weighted centroid method, the weight of the pixel points is the square of the gray value of the pixel, and it highlights the influence of the larger gray values near the center on the central position of pixels. The accuracy and robustness are good when the gray level distribution is uniform.

3. **Circular Coded Targets Recognition Algorithm Based on Decoding Endpoints.** After getting the center of the circular markers exactly, it can realize the extraction of the single circular coded target. Then, according to the encoding rules of the circular coded targets, the coded targets are decoded to obtain their coding values. Specific steps are as follows.

1) Intercept the effective area of the circular coded target image according to the center coordinates of the center circle of the circular coded targets. This effective area includes information about the center circle and the coding loop in the complete circular coded targets.

2) From the effective area of the circular coded target image, separate information of the coding loop.

3) Calculate the gray barycenter of each white coded band by using the gray squared weighted centroid method. The white coded bands are clockwise sorted by the angle between the vector of the center of gravity with the center of the circle and the X axis.

4) Extract decoding endpoint. Decoding endpoint refers to the point where the white code band is at the junction of the black code band. Extract the contour coordinates for each white ribbon to obtain the 4 coordinates of the maximum and minimum values of the row and column coordinates of the contour coordinates. Then, obtain the vectors of the four coordinates with the center points, the two coordinate points corresponding to the maximum value of the angle between the two vectors are the decoding endpoints.

5) Sort the decoding endpoint by the gray center of gravity of the white tape to make the decoding endpoints arrange in clockwise order.

6) Decoding endpoint standardization. Because of the problem of shooting angle, the coded targets have projected deformation after the camera imaging, and the decoding endpoint is extracted from the coded target after the deformation. Decoding endpoint standardization is to reconstruct the decoding endpoint on the deformed elliptical image into a decoded endpoint in a standard circular image. The reconstruction formula of the decoding endpoint is as shown in Equation (10), among which, x, y are the coordinate points of the decoding endpoint, and x_0, y_0 are the gray square weighted centroid of the coded targets, θ is the attitude angle, p_1, p_2 are the long and short axes of the circular coded target, x', y' are the reconstructed pixel coordinates, and r is the radius of the coded target after reconstructing.

$$\begin{cases} x' = r * \dfrac{(x - x_0)\cos\theta - (y - y_0)\sin\theta}{p_1} \\ y' = r * \dfrac{(x - x_0)\sin\theta + (y - y_0)\cos\theta}{p_2} \end{cases} \tag{10}$$

7) Starting with the first endpoint, obtain the angle between the two endpoints with the center point, that is the angle of each black and white code band. And then divide each angle by 30 degrees to obtain the number of bands with the unit code, finally, its number.

4. **Experiment and Result Analysis.**

In order to verify the recognition of the marked points in different shooting angles, use Canon EOS 550D camera to take pictures of the plane with the coded targets from the angle of 0 to 90 degrees to plane normal. A total of 60 images with a resolution of 2592*1728 were taken.

For coded targets, when the angle between the camera's optical axis and the plane of the coded target is larger, the imaging deformation is greater. The degree of deformation will affect the detection and identification of the coded targets. The algorithm is used to detect and identify the coded targets, according to the experimental results, the relationship between the angle ω and the recognition accuracy Prec is shown in Figure 2. The result of the recognition of the coded targets with the angles of 50°, 60°, 65°, 70° and 75° is shown in Figure 3. By analyzing the recognition results of the coded target images whose angle is less than 60°, it is concluded that the average recognition accuracy can reach 99.2%. By the same argument, the recognition accuracy of 93% is maintained when the angle is 70°. However, when the accuracy of the angle greater than 75° is rapidly declining.

In order to verify the identification of the coded targets in different fuzzy conditions, in this paper, the circular averaging filter is used to blur the image, and R is the radius of the circular region. The bigger the R is, the more blurred the picture is, and the smaller the R is, the clearer the picture is. This algorithm is used to identify coded targets that are processed by the circular averaging filter with different radii. According to the analysis of the experimental results, the relationship between the radius of the circular averaging filter R and the recognition accuracy Prec is shown in Figure 4. As can be seen

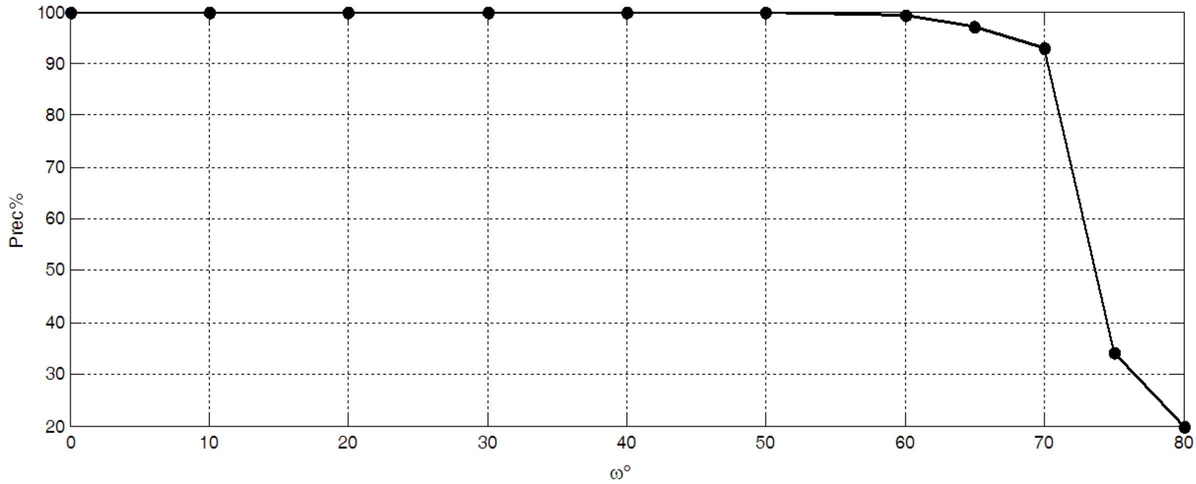
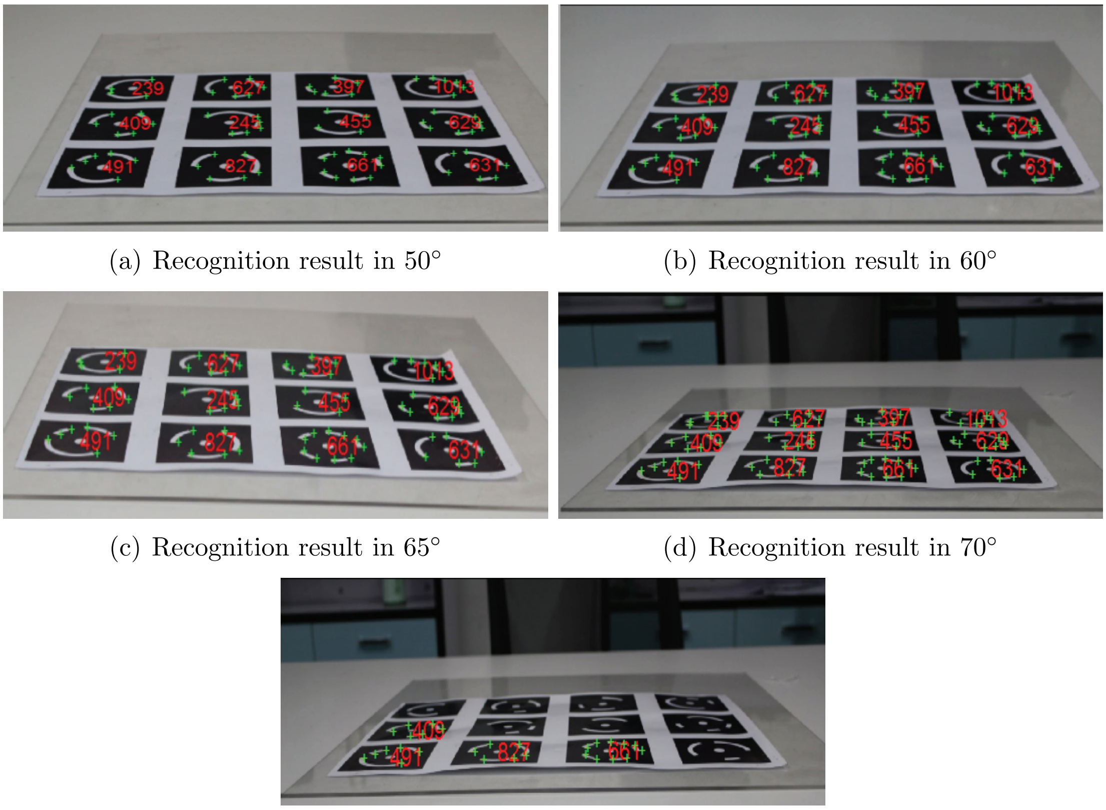


Figure 2. Recognition accuracy of coded targets in different angles



(a) Recognition result in 50°

(b) Recognition result in 60°

(c) Recognition result in 65°

(d) Recognition result in 70°

(e) Recognition result in 75°

Figure 3. Recognition results of coded targets in different angles

from Figure 4, when the tilt angle ω is less than or equal to 50 degrees, the radius of the circular averaging filter R is less than 50, the average recognition accuracy is 95%, and the recognition rate is still 80% when the radius is 55. However, when the radius is greater than 60, the recognition rate decreases sharply; when $50 < \omega <= 65$, $R <= 30$, the average recognition rate is 90.1%, and $R > 30$, the average recognition rate is less than 40%. When shooting angle is 0°, the recognition results of radius in 35, 45, 55, 65 are shown in Figure 5. When the radius is 30, and the tilt angle in 50°, 60°, 65°, the recognition results are shown in Figure 6.

In order to verify the reliability of the algorithm in complex environment, the robot with the coded targets is taken at different angles, a total of 20 images with a resolution

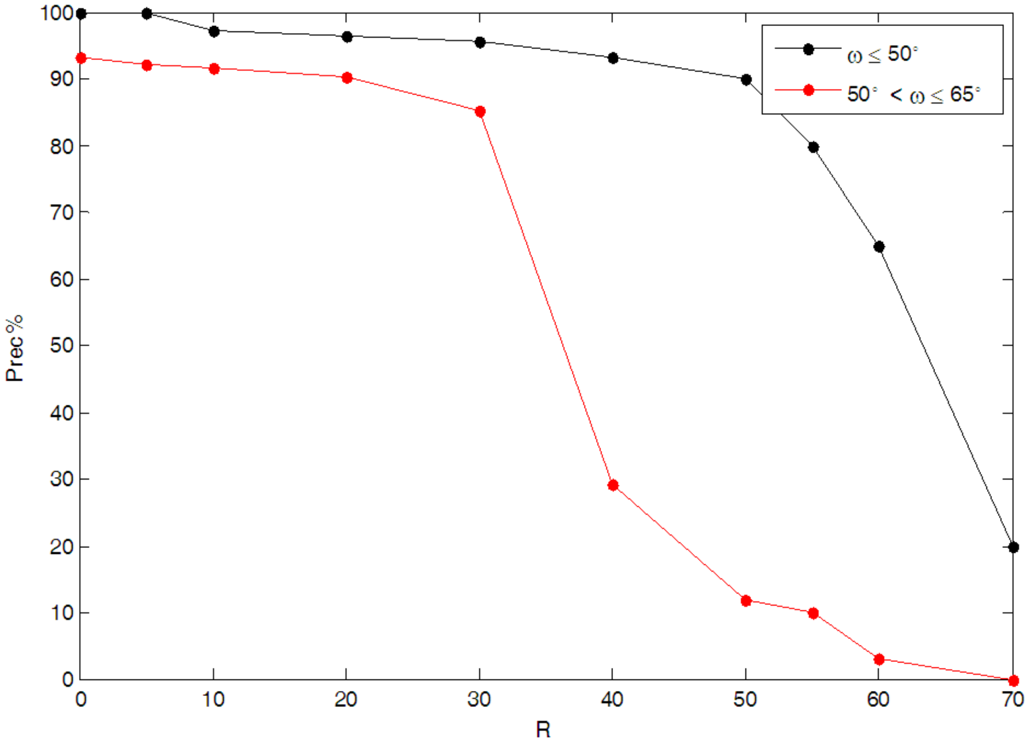
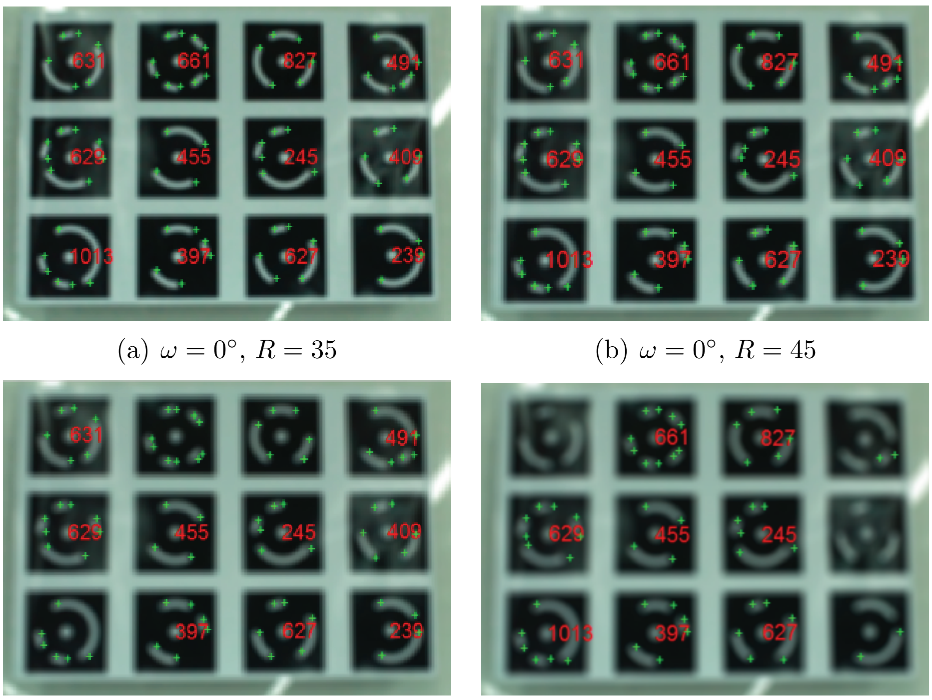


FIGURE 4. Recognition accuracy of different tilt angles at different fuzzy levels



(a) $\omega = 0°$, $R = 35$ (b) $\omega = 0°$, $R = 45$

(c) $\omega = 0°$, $R = 55$ (d) $\omega = 0°$, $R = 65$

FIGURE 5. Recognition results in different fuzzy levels at $\omega = 0°$

of 5184*3456 were taken. The algorithm is used to detect and identify them. Some experimental results are shown in Figure 7. It can be seen that most of the coded targets can be detected and identified, and few targets are not recognized because of the too large tilt angle and too blurred.

At the same time, the above 20 images were detected and identified according to the circular coded targets recognition algorithm proposed in other documents, and the test

(a) $\omega = 50°$, $R = 30$

(b) $\omega = 60°$, $R = 30$

(c) $\omega = 65°$, $R = 30$

Figure 6. Recognition results in different angles at $R = 30$

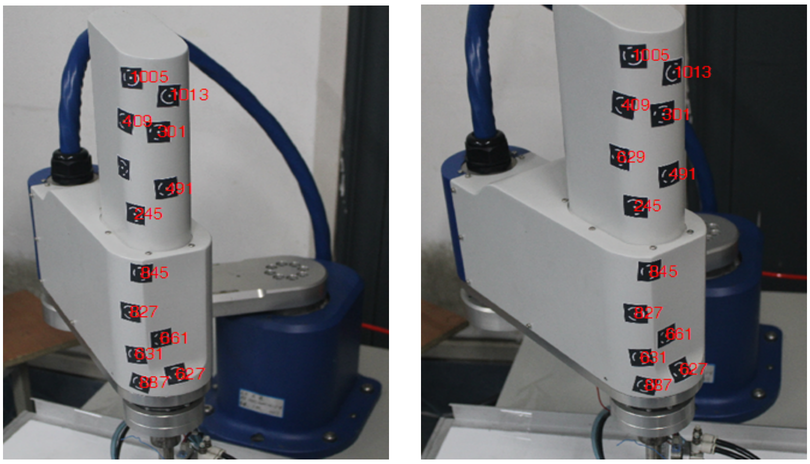


Figure 7. Recognition results in complex background

Table 1. Experiment statistics under the complex background

Recognition algorithm for comparison	Recognition accuracy /%	False recognition rate /%	Average recognition time /s
proposed	97.2	1.11	2.47
[2]	97	1.32	3.15
[6]	95.9	1.47	3.89

results are compared with the results of this paper. The recognition accuracy, the false recognition rate and the average recognition time of the algorithm are used as the evaluation criteria, and the experimental results are shown in Table 1. It can be concluded from Table 1 that the recognition accuracy of the proposed algorithm is 97.2%, the false recognition rate is about 1.11%, and the average recognition time is about 2.47 seconds. Compared with other algorithms, the algorithm in this paper has the optimal combination property.

5. **Conclusions.** In vision measurement, the stability and accuracy of coded targets identification are very important for subsequent camera calibration and 3D reconstruction.

In this paper, the gray squared weighted centroid method is used to locate the coded targets accurately. At the same time, an accurate and stable coded target recognition algorithm based on decoding endpoint is proposed by the design criteria of coded targets. The coded targets are identified by this algorithm, when the inclination angle is less than 50 degrees, the recognition accuracy is 100%, less than 60 degrees, the average recognition accuracy is 99.2%, when the angle is 70 degrees, the recognition accuracy can still be 93%. In complex background, the recognition accuracy can reach 97.2%, and the comprehensive performance is the best in the contrast algorithm. However, the accuracy of the proposed algorithm is not satisfactory under the condition of high ambiguity and large dip angle, which needs to be improved.

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