Fast Ellipse Detection and Automatic Marking in Planar Target Image Sequences

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***Abstract*—A fast method of detecting and automatic marking ellipses in the circle array target image sequences with high quality and strong regular pattern is proposed in this paper. This method collects a small amount of edge points from the ellipse by directly scanning the target image and searching for jumpy-changing of pixels, which can be used to identify the rest of other edge points by combining with the block properties of the elliptical regions, so that the expected ellipses can be calculated. The ellipse raster conversion process is then used to optimize and obtain the correct parameters of ellipses. After this, the multiple coordinate systems can be created based on the corner ellipses on the boundary of the ellipse array, and the fast marking of topological position of ellipses can also be achieved by mapping the ellipses between the different coordinate systems. The main advantage of the proposed method is that it significantly reduces the time complexity as it does not require the complex edge detection and spatial transformation operation. In addition, it is not restricted to any specific target models, and so it has very strong universality. This method is easy to be implemented, and has the high accuracy of detection. Thus, it can meet the requirements of the fast detection of the target image.**

***Index Terms*—ellipse detection, automatic marking, circle array target, image sequences, vision measurement**

I. INTRODUCTION

Planar target is a reference for locating that is widely used in machine vision systems. Extracting feature from a planar target image is the premise of camera calibration and vision measurement, and its accuracy and speed decide the precision and efficiency of a vision system. In general, there are some regular geometric patterns on the planar target, such as international checkerboard, circle array and triangle array and so on [1][2], among which circle array is the most popular one [3], and it will become ellipse array in the target image. Moreover, the geometric parameters of the ellipse are the main feature information of the target image, and therefore, the key tasks of target image processing are to detecte the feature information rapidly from the target image sequences, and then to automatically mark the ellipses so as to match them with the feature circles on the target correctly.

Most existing algorithms for the ellipse detection are limited to a single image, and few are applied to image sequences detection. At present, the algorithms for ellipse detection mainly include Hough transform and its improved algorithms[4][5][6][7], least square fitting algorithm[8][9][10], detection algorithm using geometric characteristics[11][12][13], and hybrid algorithms that combine a variety of algorithms. The advantage of Hough transform and its improved algorithms is that it has the strong resistance to the noise, but a great deal of computation is needed and the efficiency of algorithms is getting low, while least square method determines the edge points by neighborhood searching to reduce the amount of computation effectively, however this method is sensitive to noise. In [11], the geometric characteristic algorithm first locates the center of the ellipse using geometric symmetry, then uses least square method or Hough transform to get the rest of parameters, thus this enforces the efficiency of the algorithm to some extent [14]. In addition, it is essential to automatically mark the ellipses in the array for the correct matching between the ellipses in the image and the feature circles on the target. However, the current existing methods are able to identify the direction of the target by the way of adding the special tag or desingning the special structure[15][16][17], and marking is gradually extended from a special position to other positions. Although these methods can improve the marking speed, they increase the difficulty of designing and making targets, and algorithms are tedious and lacking in generality.

On the whole, the existing algorithms are generally developed based on the single complex images. Although they have the high accuracy of detection, their processing speed cannot meet the requirements of pratical applications. In this paper, the vehicle alignment vision system is chosen as a research object, and a simple algorithm of fast ellipse detection and automatic marking, which concentrating on the target image sequences of circle array with the strong regular pattern and no special structure, is proposed to meet the fast detection requirements of the vision system.

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II. Circle Array Target And Image Sequences

Circle array target is composed of multicle circles, and the centers of circles are the key feature points. Generally, the surface of a target uses the glass base, black background and white pattern for the purpose of enhancing the image contrast and improving the accuracy of the detection. The feature circles do not overlap each other, on which the special infrared reflective material is painted, so the target pattern is clear after imaging. Apart from the small amount random noise, the acquired images may accompany ellipses deformation that is caused by spot and halo, such as part deformity or bulge due to the influences of camera, light source, target fabrication, angle of imaging and so on.

In vehicle alignment vision system, the target is installed on each wheel by chucking appliance. When imaging, a camera will be required to take a photo for two targets that are on the same side of the vehicle, so each image will have two target patterns, which are located on the top and bottom of the image respectively. Furthermore, the target will be rotated and translated with the movement of wheels in 3D space, and this will cause the ellipse array in the target image to be tilted at varying degrees. The target installation and image sequences with the removed environmental backgrounds are shown in Fig. 1.

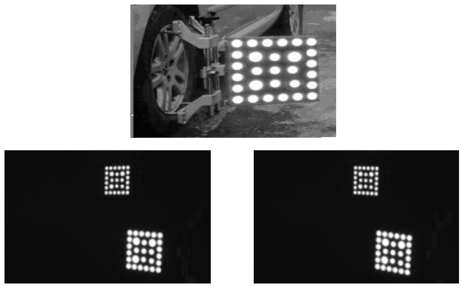


Figure1. Target installation mode and image sequences in vehicle alignment system

III. Detection Algorithm Overview

The feasure information of ellipses in the image sequences include the coordinates of the centers of ellipses, major axis, minor axis, and angle between major axis and x axis. The processing flow of feasure information extraction and automatic marking is shown in Fig. 2.

The purpose of image preprocessing is to remove the environmental background and perform the binarization. Considering that the background of target image sequences is static, firstly we use the target image, which is taken when the infrared light is turned off, as the background image, and then we turn on the infrared light, and take the other target image. After obtaining the two different target images, the difference operation is applied between the first target image using as the background image and the second target image to get the difference image. Secondly, the binary image of difference image is gained through OTSU method.

Target segmentation is aimed at dividing the target into two regions, the top region and the bottom region, so as to narrow down the range of detection of ellipse array. In this study, the target image sequences record the change of the target along with the wheels moving backwards approximately 20cm, and the object position has very small changes between adjacent frames. Thus, in this paper, only the first frame is segmented. To avoid the repeated processes of segmentation, edge pixels scanning and automatic marking, and improve the efficiency of detection, the object detection for the subsequent frames can be achieved in terms of the detection result of their previous frame and local adjustment.

Ellipse detection follows such a basic procedure: the edge points collection, the possible ellipses detection, and the ellipse authenticity verification. Based on the characteristics of target image of circle array, the proposed method directly scans the target image, and it then searches for jumpy-changing of pixels and optimizes them to obtain a small amount edge points. Moreover, these small number of edge points can be used to identify the rest of other edge points due to the block properties of the elliptical regions, so that the expected ellipses can be calculated using all edge points. The ellipse raster conversion process is then applied to optimize the expected ellipses to get the desirable ellipses, which are the most similar to the real ones.

Ellipse marking is actually to determine the topological position of an ellipse in accordance with its row and column in the array. We establish the multiple coordinate systems based on the corner ellipses on the boundary of ellipse array, and then the fast marking can be be done by the mapping of the ellipses between the different coordinate systems to determine the topological position of an ellipse in the array.

IV. Algorithms Implementation

A. Target Region Segmentation

In this paper, the two steps projection method is applied to carry out the segment of the target regions as the two target regions, the top and bottom region in the

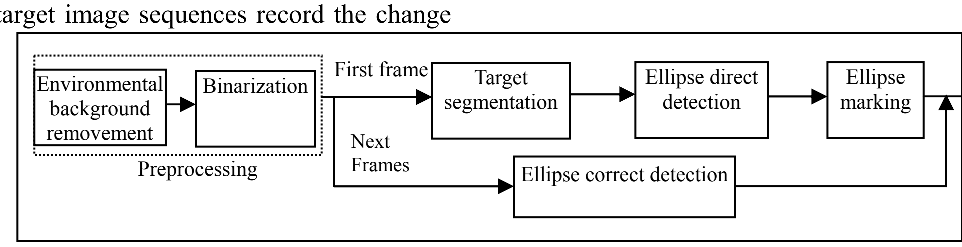


Figure 2. Feature extraction and automatic marking

target image do not overlap in the horizontal direction, and the distance between them is relatively large. Firstly, the two regions is divided by their horizontal projection. Secondly, the left and right boundaries of two target regions are able to be determined by using their vertical projection. Here only the horizontal projection process will be described briefly as follows.

Let ξ be the interval of two regions in the first frame image, δ be the size of ellipse, H be the height of image, and P be the horizontal projection set of foreground pixels. For the top region, we do a loop check for P from k=0 to H/2 to find the first nonzero point k_s of $P[k]$. If the number of successive nonzero points after k_s is less than δ, then k_s is considered as the noise and we increase the value of k to check repeatly, otherwise k_s is considered as the top boundary. To find the bottom boundary, k will need to be increased by itself to check P repeatedly, and we will then get the jumpy point k_e, which causes $P[k]$ to turn to zero from nonzero value. If the number of the successive zero points after k_e is greater than ξ, then k_e is considered as the bottom boundary. Otherwise, the checking will be repeated.

For the bottom region of image, we adopts the same method to check P from k= H-1 to H/2. Here ξ, δ and H may be given the estimated value.

B. *Ellipse Detection*

1) Edge points extraction

The basic method of object detection is to determine the boundary of an object. Generally, the image will need to be processed in a special way due to the complexity of image itself and the existence of the noise, and the complicated operation like convolution will then be applied to extract the edge points of the image. Since the ellipses are the only object graphics in the target image, and the size of these ellipses is relatively large. After the binarization, the noises that are caused by beam halo are also transformed into the blocks, which combining with ellipses in the target image, this will cause the shape of ellipse to be transformed and become irregular. Thus, any black-white jump pixels can only be the edge pixels of the ellipses blocks or the random noise. In addition, the amount of the latter is very small and it can also be erased in terms of the neighborhood characteristics. As a consequence, the edge points of the ellipse are able to be collected rapidly.

An ellipse can be described as the following equation:

$$x^2 + Bxy + Cy^2 + Dx + Ey + F = 0 \qquad (1)$$

Where, $B^2 - 4C < 0$. Therefore, the coefficients of the equation can be just determined uniquely by five non-collinear points on the ellipse curve, and then the ellipse parameters can be obtained according to the calculation relationship between equation coefficients and ellipse parameters.

The quality of the edge points of the acquired ellipse has an important influence on the solution of elliptic equations, which requires that any three points must be non-collinear, and there is a certain distance between the edge points and they should also have appropriate spatial distribution. In this paper, the first two edge points P_1, P_2, which are closed to the endpoints of ellipse's horizontal axis respectively, could be identified firstly, and the second two edge points P_3,P_4, which are the endpoints of ellipse's vertical axis intersected with P_1P_2, would then be found, as well as another midpoint P_5. The five edge points are shown in Fig.3 .

According to the radius r of the minimum circle in the target image, the interval of the line scanning ΔH is specified to be equal to $2r/5$. Assuming that white color is the forecolor, namely the color of ellipse region, black color is the backcolor, similar neighbor refers to the pixels that have the same color. For a target image, we scan it from top to bottom with ΔH interval, find and record all the foreground segments, then determine the corresponding ellipse edge points according to these line segments. The following algorithm1 is a pseudo language description for an ellipse edge point extraction.

Algorithm1: Extract Boundary Pixels

```
Input: Source image.
Output: The set of edge points.
begin
 do{
   Scan a row from left to right to find the pixel P1 with color
   jumpy-changing from black to white;
    if(P1 is the isolated noise || P1 is not spot and halo noise)
      Set P1 be the background pixel;
 }while (P1 does not exist || (P1 exists & P1 is the valid edge
          pixel));
 if(P1 does not exist) stop;
 else{
   do{Scan the white pixels toward right until reaching the
        pixel P2 with color jumpy-changing from white to
        black or the end of current row;
   }while(P2 is the valid edge pixel);
   if(The midpoint of P2P1 does not belong to the any
     ellipses that have been detected)
     {Set h←Current row coordinate; T1←P1, T2←P2;
      do{h←h+ΔH; P1←T1, P2←T2;
         Scan white pixels towards left and right respectively
          from the midpoint of P2P1 to get new T1 and T2;;
      }while(T2-T1>P2-P1);
      Scan white pixels vertically from the midpoint P of
      P2P1to get the two edge points P3 and P4 in the top
      and bottom respectively;
      if(P4-P3>P2-P1)
        {Scan white pixels towards left from the midpoint of
        P3P to get the edge point P5;}
      else
        { Scan white pixels towards top from the midpoint of
         P1P to get the edge point P5;}
        Set P1~P5 are considered as the set of edge points
         and return them;
     }}
end
```

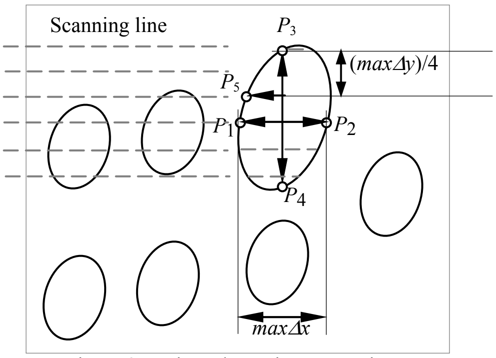


Figure 3. Five edge points extraction

The five edge points which are extracted by using the above method can meet the requirements of non collinear, see Fig. 3. Thus, an expected ellipse can be obtained by inputting the coordinates of these five edge points into the equation(1).

2) Expected ellipse verification

Ideally, the calculated ellipse, i.e. expected ellipse should be consistent with the actual ellipse. After raster conversion process, the expected ellipse will coincide with the foreground pixels of the detected ellipse in the image, or there is a higher coincidence degree between them. For this reason, all the pixels of the expected elliptic curve are generated by the ellipse midpoint raster conversion algorithm. Fourthmore, we compare the pixels with their corresponding positions in the image one by one, and then verify whether they are the edge points or not. If they are the edge points, the counter of overlap pixels will then be increased.

In this paper, the ellipse midpoint raster conversion model of the fourth section in a region is only presented due to the limitation of the maximum words (See Fig. 4).

The equation of ellipse passing through the origin is given inplicitly, by polynonaials *f(x,y)* where,

$$f(x,y) = x^2 + Bxy + Cy^2 + Dx + Ey + F \qquad (2)$$

Assuming that pixel (x_p,y_p) has been selected, the midpoint of the next pair candidate pixels is $(x_p+1, y_p+0.5)$. In this region, the direction of raster conversion is right or lower right.

Discriminant can be defined as follows:

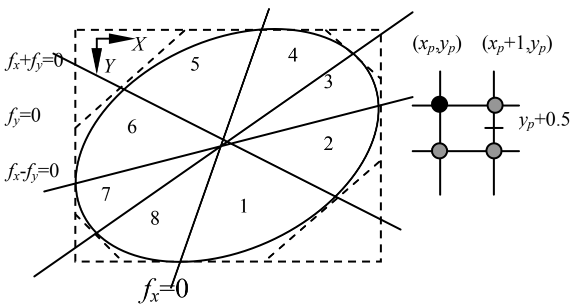


Figure 4. Ellipse midpoint raster conversion
(f_x *and* f_y are partial derivatives)

$$\begin{aligned} d_1 &= f(x_p+1, y_p+0.5) \\ &= (x_p+1)^2 + B(x_p+1)(y_p+0.5) + C(y_p+0.5)^2 \\ &\quad + D(x_p+1) + E(y_p+0.5) + F \end{aligned} \qquad (3)$$

If $d_1 < 0$, it means that the midpoint is in the ellipse, we will pick the pixel at the right and modify the discriminant as :

$$\begin{aligned} d_1' &= f(x_p+2, y_p+1+0.5) \\ &= d_1 + (B+2)(x_p+1) + (2C+1)y_p + (2C+D+E+2.5) \end{aligned} \qquad (4)$$

If $d_1 \geq 0$, it means that the midpoint is not in the ellipse, we will pick the pixel at the lower right and modify the discriminant as :

$$\begin{aligned} d_1' &= f(x_p+2, y_p+0.5) \\ &= d_1 + 2(x_p+1) + By_p + 0.5B + D + 1 \end{aligned} \qquad (5)$$

The starting point of verification can be determined by the highest point on the elliptical curve that it may be solved according to the condition that tangent slope is zero. If the starting point of verification is (x_0,y_0), then the initial value of the discriminant may be determined as follows:

$$d_0 = f(x_0+1, y_0+0.5) \qquad (6)$$

If the current midpoint meets f_x-f_y=0, the verification of the current region should be stopped and the algorithm will enter into the next region. The termination conditions of the other regions are $f_x=0$, $f_y=0$ and $f_x+f_y=0$ respectively.

When conducting verification, only the pixels of half an ellipse arc need to be generated, while another 1/2 ellipse arc can be obtained by the characteristic of symmetry of ellipse.

3) Edge points correction

Because of the effects of noise, the ellipse region after the binarization usually exists a certain degree deformation. Therefore sampling once cannot guarantee to calculate the correct ellipse. At the moment, we will need to correct the sampling points, and repeat the calculation and verification process which have been discussed above.

For each new sampling, the previous sampling points are rotated with a certain angle to retrieve a new set of adjacent sampling points. Moreover, for a given edge point, we start searching for the edge points of the fixed number(*n*) from it by a counterclockwise (or clockwise) direction, and then take the last one as a new sampling point instead of using the rotation calculation. In general, after the binarization of target image in vehicle alignment system, the number of the edge pixels in ellipse curve should be between 40 and 100. According to the expected ellipse parameters, the size of the verified ellipse may be determined. When rotating each time, *n* may be set to be $2\pi r/5$, where *r* is still the radius of the minimum circle.

We record the coincidence rate of the pixels when each verification process is conducted. After the sampling points have been rotated a quarter of a circle, we take the sampling points with the highest coincidence rate as the result. Therefore, we will need to do the rotation verification four times.

C. Ellipse Marking

The target coordinate system is created by the center of the three corner ellipses in the array, as shown in Fig. 5. Assuming that the number of the ellipses in the first and last row of the array is n, the total number of ellipses is C. Firstly, the y coordinates of the centers of all ellipses are sorted in descending order, which is considered as the set Y. Let κ_{yn} be the sequences that consists of the former n elements of the set Y, while let κ_{y1} be another sequences that consists of latter n elements of the set Y.

For all k, $1 \le k < n$, we calculate the included angle(positive value) between the line that is from $\kappa_{y1}[k]$ to $\kappa_{y1}[0]$ and x axis. Note that if all the included angles are less than three degrees, it means that the rotation angle of target is relatively small. As a result, the x coordinates of all points in the set κ_{y1} will be reordered in ascending order, and the first and last point are just P_0 and T_0. Otherwise the rotation angle of target is relatively large. At the moment, the set κ_{y1} may include the points that are in different lines. When the target is rotated clockwise, $\kappa_{y1}[0]$ must correspond to the T_0 and $\kappa_{yn}[n\text{-}1]$ must correspond to the P_1; when the target is rotated anticlockwise, $\kappa_{y1}[0]$ must correspond to the P_0. The former situation is only been discussed in this paper as the latter situation is very similar to the former situation.

Let $\xi = \max_{1 \le k < n} \{\theta_k\}$, where θ_k is the include angle between the line $\kappa_{yn}[n\text{-}1]\kappa_{y1}[0]$ and the line $\kappa_{y1}[k]\kappa_{y1}[0]$. The left corner point P_0 in the last row can be obtained through the following algorithm.

Algorithm2: Obtain Corner point P_0

Begin
Initialize a blank set S that will include the points in the last row;
Set i=0; k=C-2;
while(i<n)
{ **Let** θ be the include angle between the line $\kappa_{yn}[n\text{-}1]$ $\kappa_{y1}[0]$ and the line $Y[k]\kappa_{y1}[0]$.
if($|\theta - \xi| < \varepsilon$)
{ **Set** i=i+1; $S = S \cup \{i\}$;}
$k \leftarrow k$-1;
}
end

After the loop finishes, the x coordinates of all points in set S will be sorted in ascending order, and then the first point will correspond to P_0. In pratice, by comparing the tangent value of included angle θ_k, we may avoid calculating the real angle, where ε is between 0.5 and 1. Thus the target coordinate system *X'OY'* can be established.

Determination of the topology structure between the ellipses depends on the row and column position of their centers in the coordinate system *X'OY'*. The x axis does not usually intersect with the y axis at right angles in the target coordinate system because of the rotation of target. We define two coordinate systems *X'OY"* and *X"OY'*, see

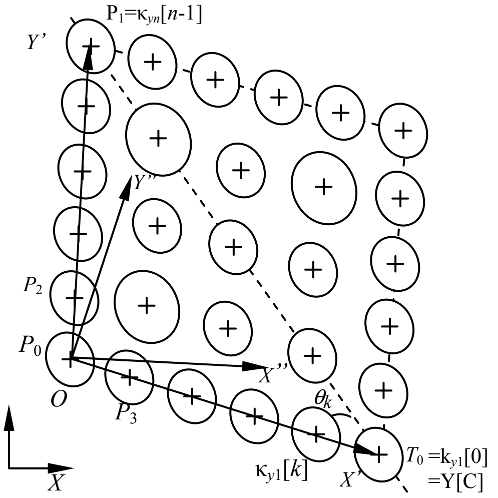


Figure 5. Target coordinate system

fig. 4. The origins of these two coordinate systems coincide with the origin of target coordinate system, and the one of their axises also coincide with an axise of target coordinate system. Thus, for any two points P_1 and P_2 in the coordinate system *X'OY'*, their relative position in longitudinal direction can be determined by y in the coordinate system *X'OY"*, while their relative position in lateral direction may be determined by x in the coordinate system *X"OY'*.

Let $P(x,y)$ be a point in *XOY* plane. The y^* and x^{**} are the y and x coordinates of its corresponding point in the coordinate systems *X'OY"* and *X"OY'* respectively. We use the two-tuples $<r,s>$ to lable the position of ellipse in the array of target image, $0 \le r < n$, $0 \le s < m$, where m is the number of the first column on the left side of ellipse array, and then <0,0>, <0,n-1>and <m-1,0> are the position tags of P_0, T_0 and P_1. Since the interval between the ellipses can be predetermined, the half of the interval between the lateral and longitudinal direction can be used as the bandwidth to map the coordinates of the center of ellipse to its matrix notation.

$$r = [\frac{y^* - \Delta^*/2}{\Delta^*}] + 1, \quad s = [\frac{x^{**} - \Delta^{**}/2}{\Delta^{**}}] + 1 \qquad (7)$$

Where, $\Delta^* = x^{**}_{T_0}/n$, $\Delta^{**} = y^*_{P_1}/m$ are the intervals of the ellipses in their lateral and longitudinal directions respectively in the ellipse array, $[x]$ denotes the nearest integer to x.

The unique code of each ellipse will be obtained by traversing all the two-tuples couples in order again.

D. Subsequent Frames Processing

Known from the correlation between sequence images, the center of ellipse in the previous frame will still be in the block of corresponding ellipse in the next frame. Thus the proposed method uses the center of detected ellipse in the previous frame as the initial search point of corresponding ellipse in the current frame, and scans the

on the basis of line P_1P_2, the algorithm will correct it toward up and down with ΔH interval to ensure that the line P_1P_2 is similar to the longest horizontal line segment. After finding P_1 and P_2, the other edge points P_3, P_4 and P_5 can also be found in the same way. Finally, all the edge points can be used to calculate the expected ellipse and then verify it.

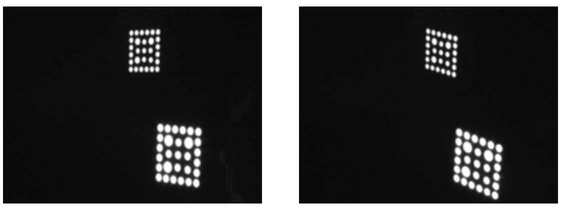
Ⅴ. Experimental Results

In order to verify the proposed algorithm, we had developed a program in VC++ language to test the real image sequences obtained from the vehicle alignment system on a PC (CPU: AMD II X4 631Quad-Core, and GHz: 2.60GHz). The resolution of these image is 744 × 480 and there are fifty eight ellipses in each image. The experiments are divided into three parts, which include detecting for the center of ellipse, marking ellipse and measuring the running time of the algorithm.

To begin with, the first experiment is to detecte the center of ellipse. The proposed algorithm and RHT algorithm presented in [7] had been applied to the first experiment respectively. Fig. 6 shows two typical images, which have a small or large tilt angle. Table Ⅰ and Table Ⅱ are the test results(The coordinates of ellipses' center on the last line of the bottom target are only listed due to the limited space). An ID number, from 1 to 6, had been given to each ellipse on the last line of the bottom target from left to right.

Moveover, the proposed algorithm was then applied to the ten successive images selected from target image sequences. The average error and maximum error between the centers of all ellipses and their true values were calculated. The results are showed as Fig. 7.

Table Ⅰ and Fig. 7 show that the proposed algorithm has high accuracy and precision, which the test results are close to the real value. The average error is less than 0.21, and the maximum error is also within 0.5. For the results of RHT algorithm, the average error of RHT algorithm is similar to that of the proposed algorithm, but the maximum errors of most images are greater than that of the proposed algorithm. Thus, the proposed algorithm is higher than RHT algorithm from the perspective of precision. The reason for this is that the quality of the selected edge points is much better. By using the selection mode of maximum line segment and the rotating optimization, we may effectively exclude the bad edge pixels such as convex or sunken edge points, and make the edge points distribute reasonablely in space.



(a)The original image 1 (b) The original image 2

Figure 6. The actual acquired of target image

white pixels toward left and right to get the two edge points P_1 and P_2 on the left and right respectively. Then,

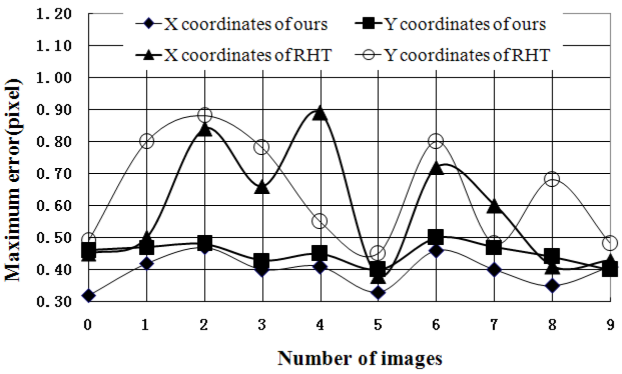
Furthermore, the second experiment is to determine the topological positions of the ellipses and give the position tags of all the ellipses. Fig. 8 shows the marking results of two targets in the bottom of images.

TABLE I.
THE CENTERS OF THE ELLIPSE ARRAY IN FIGURE5(A)

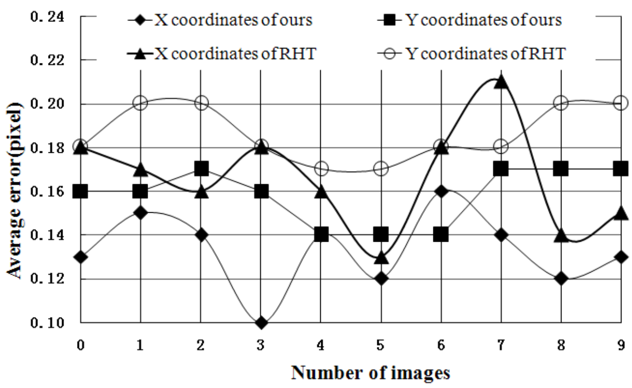
No	Ours	RHT	True value
1	(447.42,415.61)	(447.39,415.48)	(447.3,415.6)
2	(467.97,418.59)	(467.77,418.57)	(467.7,418.4)
3	(489.00,421.00)	(489.47,421.27)	(489.1,421.2)
4	(510.81,424.00)	(510.50,423.92)	(510.7,424.0)
5	(532.57,426.88)	(532.83,426.85)	(532.5,426.8)
6	(554.39,429.48)	(554.50,429.53)	(554.6,429.6)

TABLE II.
THE CENTERS OF THE ELLIPSE ARRAY IN FIGURE5(B)

NO	Ours	RHT	True value
1	(452.55,415.17)	(452.31,414.79)	(452.4,415.0)
2	(473.55,423.17)	(473.48,422.93)	(473.6,423.1)
3	(495.55,431.17)	(495.18,431.08)	(495.4,431.2)
4	(517.55,439.57)	(517.30,439.64)	(517.5,439.6)
5	(539.85,447.54)	(539.48,447.47)	(539.8,447.8)
6	(562.80,455.97)	(562.60,455.96)	(562.6,456.2)



(a) The average error



(b) The maximum error

Figure 7. Detection error of the centers of ellipses

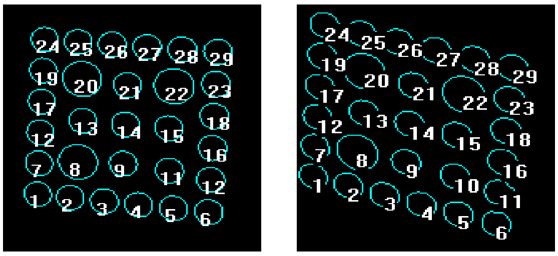


Figure 8. Marking results of ellipse arrays

In Fig. 8, the ellipses in the target have a variety of radiuses regarding the size. Thus, the arrangement of ellipse array will look irregular when rotating with a large angle. Different from the conventional marking methods, which determine the positions of special ellipses firstly, and then expand to find other ellipses, this algorithm is equivalent to determining the outer contour of ellipse array at first and then creating the clew of row and column by the coordinate transformation. Thus it does not require the ellipse on the special position and direction mark, the method of automatic marking for the ellipse array is more generic.

In addition, the time of this marking method is mainly used for the determination of array corners in the beginning of the marking process and the ordering of the coordinates of the ellipses' center. However, the proposed algorithm has spent the less time on this, because the transformation of the coordinates of the ellipses' center can be avoided calculating repeatedly by the values of the precomputed trigonometric function, and the following ordering will only use several elements from the ellipse array. Hence, the proposed algorithm has the better efficiency.

Last, the third experiment is to measure the time of detection for image sequences. The ten selected successive images in first experiment had been used as the test objects. Each of the two algorithms, the proposed algorithm and RHT, had been applied to run for one hundred times to obtain the average detection time, which is shown as Table III.

TABLE III.
DETECTION TIME OF THE PROPOSED ALGORITHM(MS)

No.	Ours(ms)	RHT(Without marking)
1	18.754	19.457
2	9.915	19.535
3	9.645	19.456
4	9.686	19.418
5	9.534	19.347
6	9.581	19.651
7	9.518	19.548
8	9.816	19.471
9	9.586	19.756
10	9.695	19.483
Average time	10.573	19.512

Table III shows that the detection time of the first frame is 18.754 ms, which includes three parts: the target segment, the ellipse direct detection, and ellipse marking. Compared with the first frame, the subsequent frames have much less detection time, and the average time of detecting one of sequence images is 10.573 ms, which is about 1/2 of detection time of RHT without ellipse marking. Thus, the proposed algorithm has the better detection efficiency. The main reason is that this paper has fully considered the characteristics of the presented issues, which the target image has the better quality and strong regular pattern. The proposed algorithm abandons the edge detection and spatial transform operation of the traditional algorithms, but determines a small amount of edge points in terms of scanning the images directly, and then expands to find other edge points. Moreover, the voting process of other algorithms is not adopted in this paper, and the verification just depends on the scan conversion of ellipse contour, which greatly reduces the amount of calculation. In addition, the processing of subsequent frames avoids the repeated segmentation, edge pixels scanning and automatic marking, which also improves the efficiency of detection.

VI. CONCLUSION

In this paper, we have proposed a fast method for ellipse detection and automatic marking in the target image sequences, which fully takes advantage of the characteristics that the acquired target images from a vision system only have a small amount noise and the black-white regions of images are relatively large and concentrated after the binarization, and it can quickly collect some edge points to compute the expected ellipses, and then optimize them by using the ellipse raster conversion process. Moreover, this method advoids the problems of a larger number of detected objects and complex computing in the conventional edge detection methods and the random selecting points methods, and is able to select the good quality of edge points and detecte the ellipses of target with smaller time cost and higher precision. Only based on the outer contour of the array, automatic marking algorithm is capable of marking the topology position of the ellipse array, regardless of the target patterns. Experimental results show that the proposed method is simple and fast, which can meet the fast detection requirements of vision detection systems, such as vehicle four wheel positioning.

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