Vision-based Automatic Archery Target Reporting System

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Abstract: Archery is a classic sport with a long history. Most competitions adopt manual target reporting system, which is time consuming, and less efficiency in data processing. This paper presents a vision-based automatic target reporting system for archery through OpenCV. By using the improved corner detection algorithm to eliminate unnecessary parts of the image and combine with the template-matching method, the accuracy of the obtained corner coordinates has been increased. On the other hand, by analyzing various complex cases that might occur in archery competitions, a newly developed judging and calculation method for arrow tip has been employed that makes the system more complete and adaptive. The designed automatic target reporting system has the advantages of convenient installation, low cost and efficient which can effectively overcome the shortcomings of manual target reporting system in the past. The proposed system has been tested by images in different situations, and the results show that the target accuracy rate reaches more than 97%. It could be applied to other sport competitions.

Keywords: Image correction, OpenCV, Archery, Automatic target reporting system

1. INTRODUCTION

Archery is a classic sport with a long history. It is one of the important events in the Olympic Games, Asian games and other large-scale competitions [1].

In the Olympic archery competition, the distance of both male and female competitors is mostly 70 meters. The target is placed at the end line, with an included angle between 75 and 80 degrees to the ground, and the height of the target center is stipulated to be 130 centimeters as shown in Fig 1.

There are 10 concentric rings on the target face to indicate the number of scores. The color of every two rings in the 10-ring target face is the same. From inside out are yellow, red, blue, black and white, as shown in Fig.2.

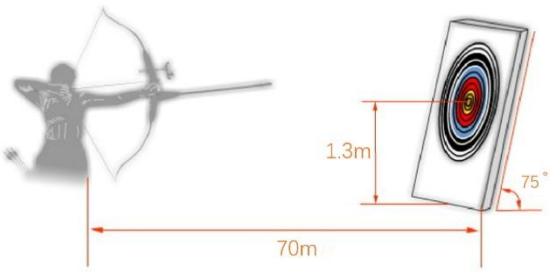

Fig. 1 Archery competition setup

The distances between each rings are the same, which equals to 6.1 cm. There is a small central ring in the 10-ring area, called the inner 10-ring. When shooting the inner 10-ring, the score is X10. If the score of archery competition is them same, X10 is used to determine the final rank. When the arrow hits the loop line, we judge it a high loop value. That is, when shooting to the outermost ring line, it is denoted as hitting 1 ring. If the next arrow hits the previous arrow, the score is based on the result of the previous arrow. If an arrow hits the target and then falls off, the score is calculated from the marks left on the target face [2].

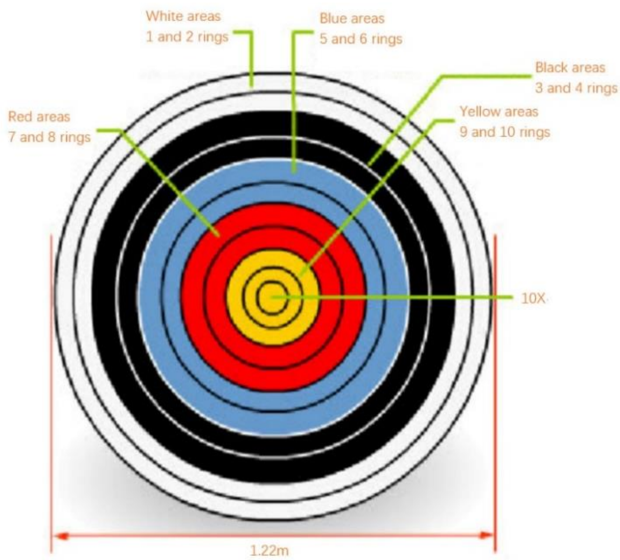

Fig. 2 Standard 10- ring target face

At present, archery target reporting is mostly done by human manual operation. It is time consuming and less efficiency for further data processing. In addition, the observation of human eyes is prone to errors that lead to affect the competition scores.

Many researchers develop some automatic target reporting systems. Some systems set up sensors on the target to determine the score, such as the photoelectric automatic target reporting system [3]. However, these systems usually cost expensive and the setup demands more for the environment. Other systems use computer vision techniques to process the target images to get the result [4]. However, they omitted to deal with the complex situations, which are often appear in competitions, such as shadow, falling off, multi-arrow etc. Therefore, the obtained target data is not accurate enough.

In order to solve these problems, this paper presents an automatic target reporting system based on image processing technology, which has the advantages of convenient installation, low cost and especially the ability to deal with varied complex situations to reach an accurate result.

2. Design Scheme of Vision Based Automatic Target Reporting System

Considering the hardware cost, installation convenience and accuracy of the automatic target reporting system, this design adopts a single camera to take target face pictures. The camera is required to capture the target and arrow clearly. Because 2D images do not contain depth and other information, we need to carry out a series of processing on the image to identify the ring value. The flow chart of the automatic archery target reporting system is shown in Fig 3.

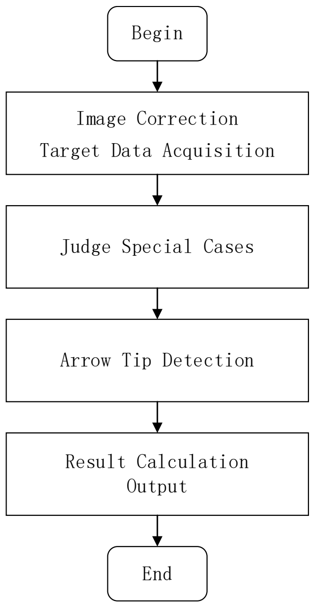

Fig. 3 Flow chart of the automatic target reporting system

The detailed steps of image recognition process based on OpenCV can be divided into four steps as followings:

Step 1 Correct target images and obtain target data. The image is corrected by filtering, corner detection and perspective transformation. Then, the center coordinates and radius of the target face are detected by Hough transformation.

Step 2 Detect the arrow tip coordinates. Use frame difference method to get the image of arrow. Determine whether there is shadow, fall, block and other conditions, and then to determine the arrow tip coordinates.

Step 3 Determine the number of rings. Use the arrow point coordinates obtained in step 2 and the center coordinates obtained in step 1. The distance between the tip of the arrow and the center of the circle could be calculated. Compared with the radius, the corresponding ring value of the arrow tip is obtained.

Step 4 Analysis of special situations:

1) The shadow cases. Considering the shadow of archery on the target face when the event holds in outdoor and under sunlight. In this case, there would be two line segments in the image after the frame difference. We need to calculate the equation of the two line segments first. Then calculate their intersection point, which corresponds to the arrow tip coordinates.

2) Arrow falls off cases. During the competition, arrows might fall off after hitting the target face. According to the rules, the result is calculated according to the point where the arrow hits the target face [5]. In this case, we detect the small round hole left by the falling arrow to determine the ring number.

3) Multi-arrow cases. If there are multiple arrows on the target, one of the arrow might be covered by other arrows in front of it. If they are in partial transverse position in the middle of the arrow, as shown in Fig 4, only the truncated parts need to be connected, which would not affect the arrow tip recognition. However, in some cases, the tip of the arrow might be hidden, as shown in Fig 5. The true position of the arrow tip cannot be determined only from the image. Therefore, we need to calculate the coordinate of the arrow tip through the data of the arrow obtained before.

Fig. 4 Arrow shaft is obscured

Fig. 5 The tip of arrow is obscured

3. PROGRAMMING BASED ON OPENCV

3.1. Target Image Correction

Since the camera-shooting angle and other installation problems, the images generated by camera will include some geometric distortions, such as barrel shape, pillow shape, trapezoid shape and image distortion. Therefore, we need to correct the captured images first.

The interested area is target face, the background is considered as noise. Therefore, we should intercept the images first to reduce the interference of noise through the adaptive Region of Interest (ROI) method [6]. The target face is white and the color of the target is black. We do not need the information of the rest of the image. Therefore, we intercept the target face area by ROI, which could greatly reduce the interference of noise. Therefore, the input image of the system includes all quadrilateral target face, but does not include other pixels outside the target. Picture taken by camera is shown in Fig 6, and the picture after ROI is shown in Fig 7.

Fig. 6 Target face picture taken by camera

Then we convert the image after ROI to gray image, and binarize the image. The result is shown in Fig 8. The aim is to detect the four corners of the target face. When using corner detection to the image, the black ring area in the target face will interfere the detection. By filling the target face area with white color and filling other area with black color first, the noise will be reduced greatly. The result is shown in Fig 9. All corner points detected are at the edge of the target face.

Fig. 7 Picture after interception

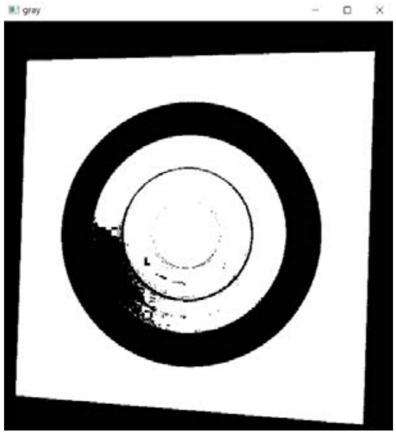

Fig. 8 Image after binarization

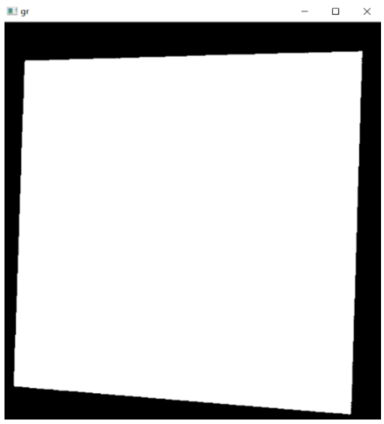

Fig. 9 Image after filling white color

We use the template shown in Fig 10 to match all detected corner points. If a region is all white, and the opposite side region, the two regions perpendicular to the region are all black, this corner point is the corner of the target face [7]. This method can eliminate detected false corner points at the sub-pixel level. When the precision of the camera is not high enough, the phenomenon as shown in Fig 11 will occur.

Some angles of the archery target face are round, resulting in multiple corner points being detected. In this case, we can calculate the median of these corner points as the corner point we need.

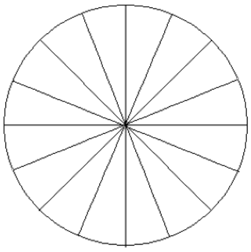

Fig. 10 Matching template

Fig. 11 Round corner

After the four corner coordinates of the archery target face are obtained, we set the correction coordinates of these four points to correct the image through perspective transformation [8]. Since the target data acquisition needs the image after the edge detection, we correct the result figure of Canny edge detection. The correction result is shown in Fig 12.

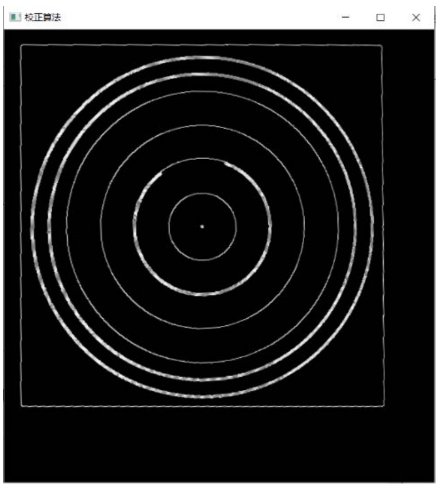

Fig. 12 Image after correction

3.2. Target Data Acquisition and Arrow Tip Detection

After image correction, all 10 circles in the archery target face are corrected to be positive circles. In addition, the morphological filtering widens the loop line. We can use Hough transform identification algorithm to detect the center and radius of the circle easily [9], as shown in Fig 13.

Through setting the detection function parameters, the detected ring is the outermost ring. The coordinate and the radius of the outermost ring could be obtained by the feedback of the function. Since the ten rings of archery target face are equally distributed, the ring width between each ring is the radius of the outermost ring divided by 10.

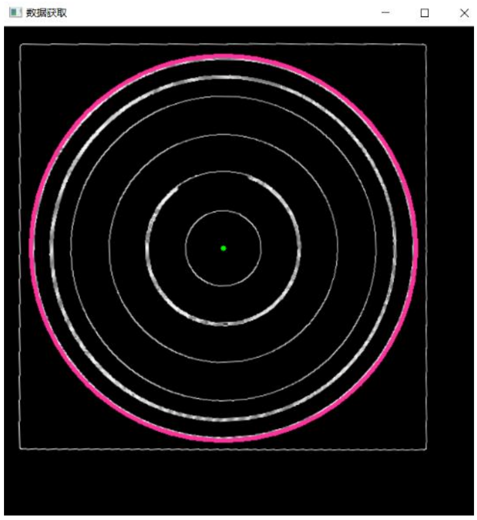

Fig. 13 Circle detection

Because both the target and the camera are fixed, so the background of the image is the same before and after the shooting of the arrow. Only the arrows on the target change. Therefore, we can use the frame difference method to obtain the image of the arrow so as to recognize the arrow tip coordinates.

The calculation formula of the frame difference method is shown in Eq. (1).

$$D_t(x,y)=\left|I_t(x,y)-I_w(x,y)\right| \tag{1}$$

where I_t is the image after finishing shooting, I_w is the image before shooting, and D_t is the result obtained by frame difference method.

The image is processed by binarization and filtering. Use the binarization function to process the image, and the binarization formula is shown in Eq. (2). Because the color of each ring of the archery target face is different, the brightness of each part is different after the frame difference. The gray value of some parts is less than the threshold obtained by the adaptive threshold algorithm. Therefore, we need to set a lower threshold manually. All parts of the arrow can be detected.

$$W(x,y)=\begin{cases}1 & D_t(x,y)\geq T\\ 0 & D_t(x,y)<T\end{cases} \tag{2}$$

where D_t is the result obtained by frame difference method, T is the threshold value, W is the image after binarization.

Do the same perspective transformation of this image as the previous image correction. Then we can use the Hough transformation algorithm to identify the line segment and obtain the endpoint coordinates of both ends of the arrow. Assuming that the camera is shooting on the right side of the archery target face, so the right endpoint of the arrow is the arrow tip. The identification image is shown in Fig 14. The ring value can be obtained by calculating the distance between coordinate and radius of the center of the circle.

Fig. 14 Frame difference and detection arrow point coordinates

4. Solutions for Some Complex Cases

Case 1 Arrow shadow cases. When some special situations happened, such as shadow, arrow falling off after hitting the target, and the arrow tip being shielded, by using previous algorithm might lead to misjudgment, which will affect the recognition results of the automatic archery target reporting system. In this paper, a discriminant algorithm has been chosen to judge whether there is a special case, and uses relevant algorithms to detect and calculate the ring numbers.

While archery competition is played outdoors, shadows appears inevitably. For every arrow that hits the target, there is an arrow shadow of its own. When the image is processed by frame difference method, two line will be jointed at one point, as shown in Fig 15. We use Hough transform to detect the line segment and then the equations of two lines are obtained, which correspond to the arrow and its shadow. Then we can calculate the intersection point of two lines, which is the coordinate of the arrow tip.

Fig. 15 Frame difference detection of shadow case

Case 2 Arrow falls off cases. If the arrow is not strong enough to hit into the target face and falls off, or if the arrow is too sharp and go through the target, when these two situations occur, there will not be any arrow on the target, only the arrow hole left on the target face. After using the frame difference method, a dot is obtained [10]. We use morphological filtering to eliminate noise. Then detect the dot coordinate, which is the arrow tip coordinate.

Case 3 Multi-arrow cases. The archery in the competition is a group of six arrows, so the shaft of the arrows might be blocked for each other. During the detection process, we will save the pixel area of each arrow. If the comparison shows that the current arrow overlaps with the previous recorded area, the occlusion may happen. If the right-most pixel area of the current arrow is not connected with the recorded area, it is only the middle or tail of the arrow shaft that is blocked. By setting the appropriate parameters, the program of recognizing line segments will automatically ignore the discontinuity, which will not affect the identification of the arrow tip.

If the right-most region is connected with the recorded area, there might be the situation that the arrow tip is occluded, and the identified arrow tip coordinate may not be the real coordinate. For example, in Fig 16, the actual result of the occluded arrow is nine, but the frame difference judgment is eight, which is the wrong result.

In this paper, we present a method for dealing with this situation. When detecting the coordinate of the first arrow tip, we record the coordinate of a feature point on the arrow, such as the special point on the arrow feather. Then the ratio between the distance from the feature point to the arrow tip and the distance from the feature point to the nock of the arrow could be obtained. This ratio is fixed and constant. Therefore, after obtaining the coordinates of the feature point and the nock of the current arrow, we can calculate the coordinate of the arrow tip through the fixed proportion.

Fig. 16 The arrow tip occlusion

By analyzing the characteristics of three cases, the resulted image after frame difference can be used to judge the special case. If two line segments are detected, it is the case that there is shadow. Whether or not there is occlusion, the arrow point coordinates can be obtained by calculating the intersection point. If no line segment is detected, we can process the image by filtering and detect whether there is a dot; if not, it is missing; otherwise, it is falling off, and the dot coordinates are the arrow point coordinates. If only one line segment is detected, according to the above method, we can know whether there is arrow tip occlusion; if not, calculate normally; if there is occlusion, calculate the real arrow tip coordinates.

5. Experimental Results

After the system is programmed, we test the automatic target reporting system to verify its effectiveness and performance. Through several groups of random pictures, the accuracy of the system has been demonstrated.

In normal conditions, the automatic archery target reporting system can get the results accurately and quickly, as shown in Fig. 17.

Fig. 17 Normal test results

In the shadow cases, the result is also accurately identified, as shown in Fig. 18.

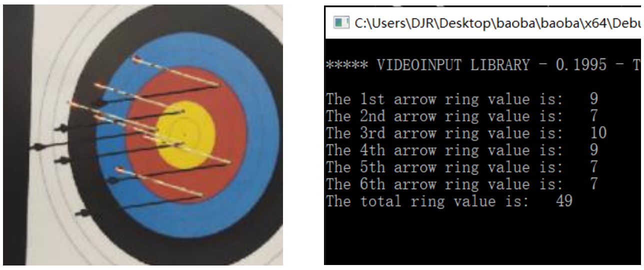

Fig. 18 Shadow case test results

In the case of arrow tip occlusion, because we need to calculate arrow tip coordinates, the accuracy is related to the coordinates of feature points. Therefore, there would be some errors, but most of the detection results are accurate, as shown in Fig. 19.

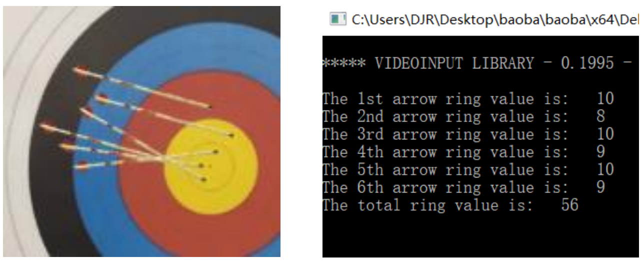

Fig. 19 Arrow tip occlusion test results

We define the target accuracy rate as performance index:

$$\text{Accuracy rate} = \frac{\text{The number of correct identification}}{\text{Total number of the test}}$$

Overall, the results show that the target accuracy rate reaches more than 97%.

6. Conclusion

This paper studies automatic archery reporting system based on vision and OpenCV. We completes the algorithm design and software development of the system. Firstly, we use the improved corner detection algorithm to detect the corner and correct the target image taken by the camera. The image distortion problem has been solved, and the target correlation data is obtained by detecting algorithm. Secondly, this paper studies in detail for some complex cases in target face during archery competitions, and completes the judgment algorithm and arrow tip coordinate detection algorithm, which improves the recognition accuracy of the system. Finally, by using OpenCV and image processing technology, an automatic target reporting system for archery has been achieved that can determine the result efficiently and accurately.

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