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Two-stage Computer Vision Assisted Automatic Archery Scoreboard Scoring System

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***Abstract*—Archery is a precision sport that requires high consistency and accuracy. The score's consistencies are highly correlated with respect to the archer's shooting pattern. With the current advancement of technology, archery scoring remains manual using scope observation in the field. By leveraging computer vision, recent efforts are made to automate the scoring process with the use of cameras. Previously studied computer vision approaches primarily explored processes such as homography estimation, image subtraction, and circle detection. However, these approaches do not accommodate the real target board faces, highly skewed camera angle, and estimated circles that may deviate from actual target rings. In this paper, a two-stage automatic archery scoreboard scoring system is proposed to detect arrows using camera. Firstly, the initiation stage extracts the scoring areas of the target ring by incorporating curve interpolation. Subsequently, the operation stage detects and localizes an arrow in consecutive frames. The proposed method demonstrates accurate arrow extraction from the target ring with less susceptibility to noise. It is able to operate consistently in challenging conditions due to an isolated detection stage.**

***Index Terms*—Archery, Automatic scoring system, Computer vision**

I. Introduction

Archery is one of the precision sports that requires a combination of physical skill, mental focus, and precision aiming in the arena due to its competitive nature. Various studies [1]–[4] are performed on the posture consistency and shooting patterns leading towards the archer's score. These studies includes vision impaired athlete [5], [6], score prediction system [7], and scoring systems [8]–[10]. Archery target faces consist of ten concentric circular rings, with the innermost ring worth 10 points and the outermost ring worth 1 point. Most archery competitions perform their scoring system counting manually using scope observation. Due to the recent advancement of technology, many attempts are made in order to automate the scoring system with instant score reporting systems, such as [11] reported by Hyundai Group. However, this instant score reporting system is not widely used in the field as it requires robust and steady detection method.

To automate the scoreboard scoring system, numerous studies are developed based on image processing. Automatic scoring system using image processing is generally divided into five basic steps in the process i.e. image pre-processing, scoreboard detection, circle detection, arrow detection, and scoring counting. Rudzinski et al. [12] proposed an automatic scoring system based on image processing with no additional gear in. The system is mainly developed based on Prewitt edge detection and Hough transformation. Nguyen et al. [13] proposed a line and gap information to locate and orient the arrow and pinpoint the piercing point on the target. Zin et al. [14] proposed an automatic scoring system with an image subtraction technique. This technique involves mathematical morphology operations such as dilation and erosion together with dynamic thresholding on colored and gray images. On the other hand, Peng et al. [8] proposed the use of a deep learning model for smartphone-based archery scoring system.

In spite of proposed works [8], [12]–[14] in automating the arrow scoring system, they require optimal conditions to operate, such as a clean target face, lightly skewed camera angle, and rely on circle detection, for instance, Hough transform. This paper proposes a two-stage algorithm for arrow scoring automation and aims to avoid the reliance on circle detection such as Hough transform, as circle detection can estimate an incorrect ring when abundant of noises are present such as a heavily used target face. Secondly, the proposed method is designed to be able to operate in a skewed image, as this provides flexibility on the placement of camera to take footage of target face. Lastly, the proposed method can be operated on a heavily used target face, hence less susceptible to noises from the used target face.

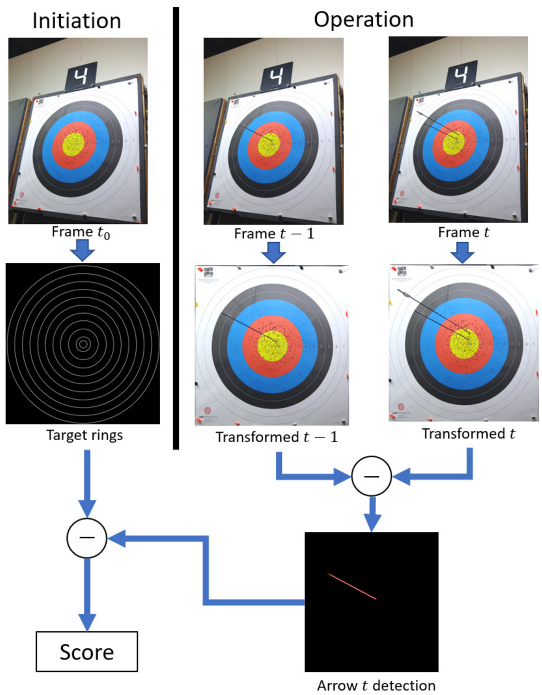
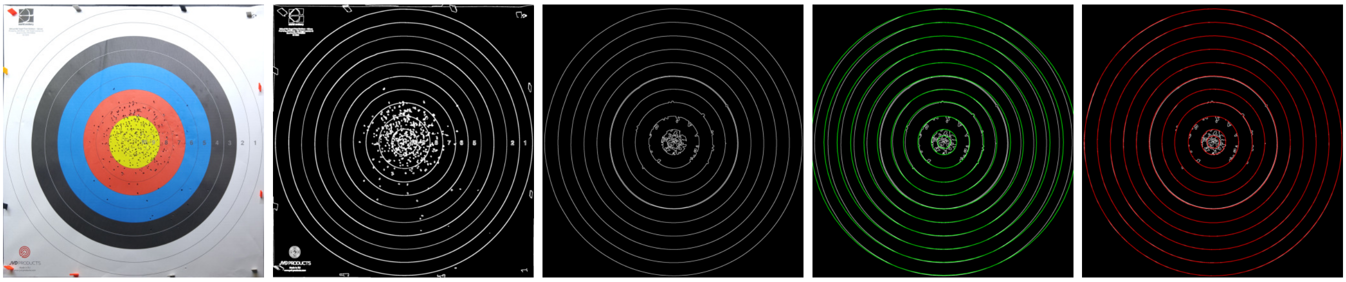
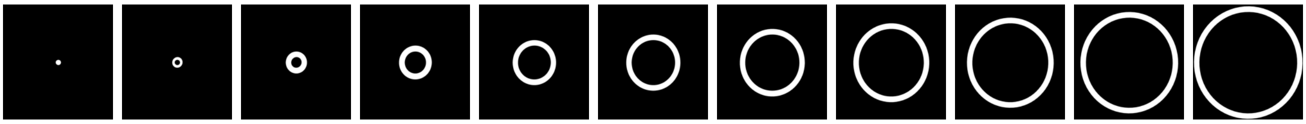


Fig. 1: Two-stage proposed algorithm in automatic score detection.



(a) (b) (c) (d) (e)

Fig. 2: Image pre-processing on input frame t_0: (a) Perspective corrected input image, (b) Raw contour, (c) Filtered contour, (d) Iterative circle fitted, (e) Curve interpolated contour (ours).



(a) (b) (c) (d) (e) (f) (g) (h) (i) (j) (k)

Fig. 3: Illustration of scoring areas generated using extracted target rings.

II. Proposed Automated Scoreboard Scoring System

The proposed automated scoreboard scoring system can be generally split into two stages: (a) the Initiation stage takes an image of an empty target face to extract each ring band for arrow scoring, (b), the Operation stage comprises stages of image processing to detect and locate respective arrow on frame t relative to its previous frame $t-1$ as shown in Fig. 1. The reason of splitting into two stages is to isolate the estimation of both the ring scoring area and the arrow piercing location. This is crucial to avoid redundant computation resources in each consecutive frame resulting from repeating homography estimation in every frames for the canonical transformation. Moreover, automated homography estimation in each consecutive frame may cause image transformation inaccuracy due to occlusion caused by multiple overlapping arrows. In addition, the two-stages strategy also isolates the arrow detection relative to the target face. Subsequently, the operation stage takes consecutive frames t and $t-1$ for arrow detection. Once an arrow is located, it is traced back to the extracted scoring areas in the Initiation stage by searching the area of intersection between scoring areas and localized arrow.

Fig. 4: Annotated target face for initiation stage, where $1, 2, 3, 4$ are vertices of target face, and vertex 5 is the bull's eye.

In the following subsections, the algorithm flow of each stage is elaborated in detail.

A. *Initiation stage*

The aim of the initiation stage is to extract scoring areas of a desired target face and obtain a coarse homography transformation for consecutive frames. Difficulties from this stage can be realized in two folds. Firstly, highly skewed input images due to various camera angles may render inconsistency in homography estimation. Secondly, the noises present on a used target face, where existing pierced holes may affect the extraction of scoring points. To overcome the inconsistency in homography estimation, four vertices of the target face are manually annotated at frame t_0 to obtain a coarse homography transformation. The fifth vertex is annotated at the bull's eye radius. Using the annotated vertices, the target face can be cropped and transformed as illustrated in Fig. 2a. This cropped target board is set as canonical form relative to all consecutive frames. Assuming the camera angle is constant throughout the shooting session, this ensures consistency in obtaining the target face in all frames.

Subsequently, Canny edge detection is applied to obtain the edge features as illustrated in Fig. 2b, and the respective filtered contours are obtained as illustrated in Fig. 2c. The contour filter is determined by using the bull's eye radius defined during vertex annotation. Commonly, a circle detection approach, such as Hough transform can be implemented to estimate the target rings to determine a target face scoring area. However, Fig. 2d shows the estimated circle (in green) does not fit the target ring's contour. This is explicitly due to the cropped target face is not perfectly unskewed from the annotated vertices. In this work, an alternative approach is devised to estimate the target ring by first smoothing the contour via interpolation and subsequently estimating its convex hull as illustrated in Fig. 2e. Lastly, the scoring areas can be defined by intersecting each target rings as illustrated in Fig. 3.

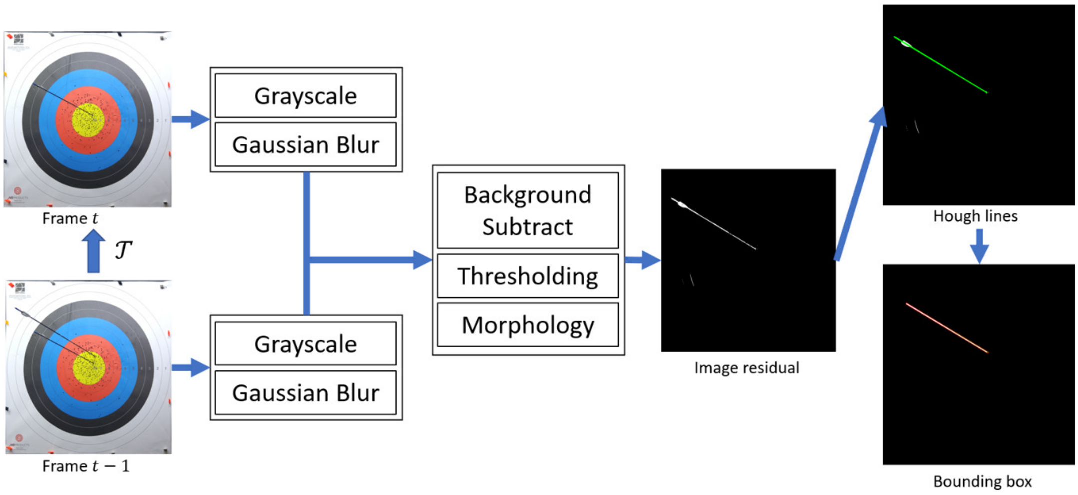
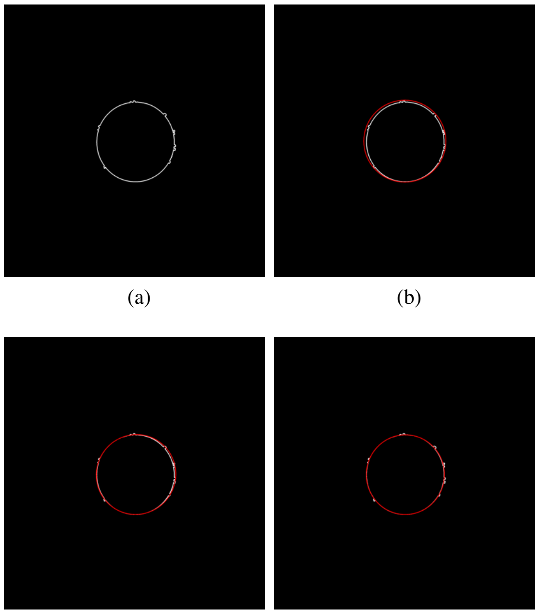


Fig. 5: The arrow detection flow during operation stage.

B. Operation stage

In operation stage, it is aimed to localize an incoming arrow on a consecutive frames $t-1$ and t as illustrated in Fig. 5. Prior to image processing, each frame is cropped and transformed using the coarse homography obtained in the Initiation stage. Next, a fine homography between the frames is estimated by an affine transformation $\mathcal{T}$. This step is crucial in aligning the frames in order to reduce residual noises during image subtraction. The frames are converted into grayscale and Gaussian blurred to further reduce noises while preserving significant features. Subsequently, image subtraction is performed, followed by binary thresholding, and a series of morphology such as image erosion and dilation. Assuming each frame t only contains one arrow, the residual from image subtraction is used to localize the arrow. Hough transform on probabilistic line detection is implemented, followed by bounding box estimation of the detected lines. The orientation of the detected arrow can be defined by soft-defining the camera orientation. Lastly, the score can be determined by searching the intersection between localized arrow and scoring areas.



(a) (b) (c) (d)

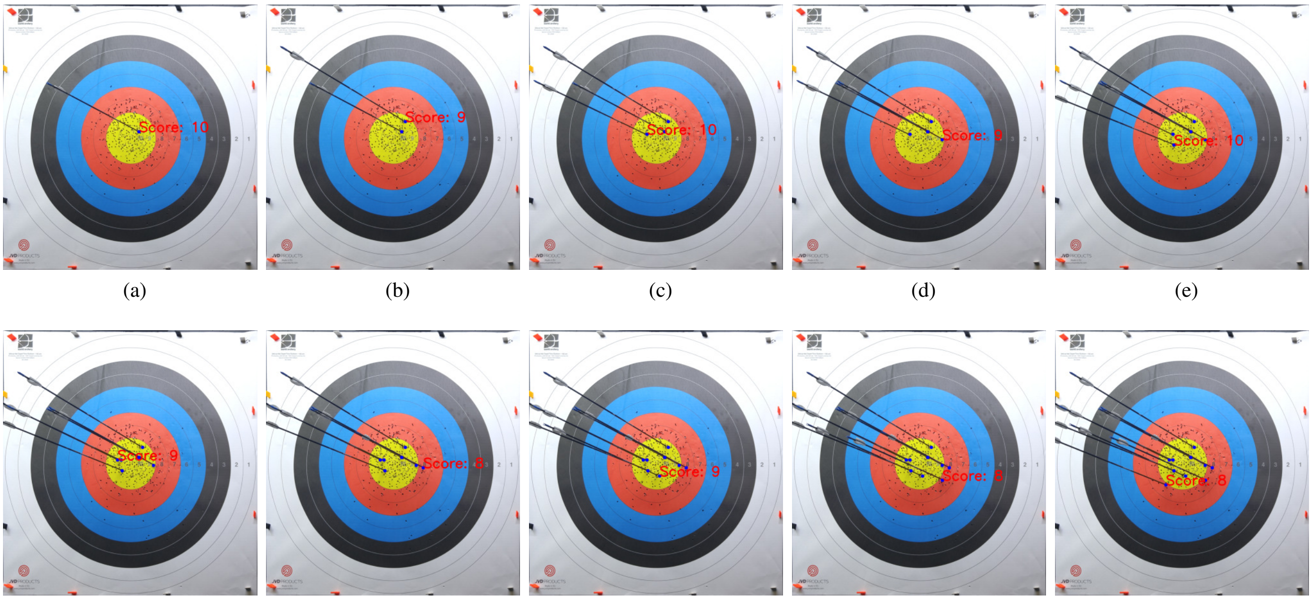
Fig. 6: Illustration of ring estimation on 4^{th} target ring: (a) Raw contour, (b) Iterative circle fitted, (b) Iterative ellipse fitted, (d) Curve interpolated contour (ours).

III. Results and Discussion

For system scoring evaluation, Fig. 7 shows a series of scoring results on one of the most challenging archery session. This session involves a heavily used target face, with the presence of multiple occluded arrows during the session. For instance, Fig. 7d and Fig. 7f showed correct scoring despite a complex condition where multiple arrows are occluded. Benefiting from the nature of isolated detection of target rings and arrows, each consecutive frame is constrained for single arrow detection, hence this enhanced the localization of each arrow. In spite of the presence of multiple occlusions, the system performed consistently producing correct scores.

For target ring extraction evaluation, noises are unavoidable in a used target face, hence combination of curve interpolation and convex hull is implemented to extract the close estimation of true target ring. Fig. 6 shows an instance of estimation on 4^{th} target ring, where Fig. 6a shows the raw contour of 4^{th} target ring with presence of noise, i.e. edge features from the existing pierced hole. Fig. 6b shows results of circle detection using Hough transform and Fig. 6c shows results of convex hull estimation on the raw contour. It is observed the target ring is deviated due to noises which can cause false localization of an arrow on a scoring area. Intuitively, by incorporating curve interpolation and convex hull, a closer estimation is achieved as illustrated in Fig. 6d.

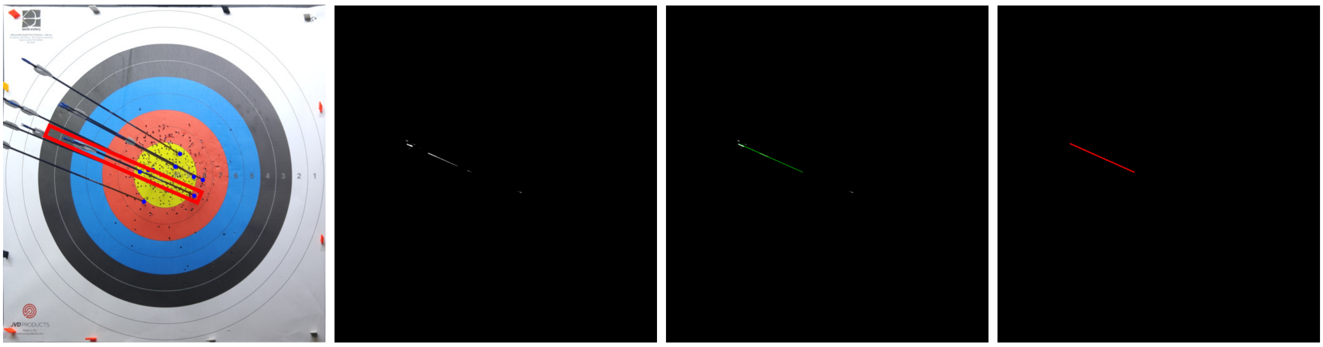
As the extracted target rings are close to identical to the real target ring, minor image skew that is inherited in the consecutive frames can be neglected because it does not affect the localization of the arrow relative to its true position in the target face. This is due to skewing of an image is an affine transformation that affects image pixels globally, and the estimated target rings in this proposed work skew proportionally to the input image as illustrated in Fig. 2e. In contrast to existing works, where circle detection is implemented using



(a) (b) (c) (d) (e)

(f) (g) (h) (i) (j)

Fig. 7: Results of automated scoring in an archery session.



(a) (b) (c) (d)

Fig. 8: Illustration of the failed case: (a) Residual from image subtraction, (b) Hough transform probabilistic line detection, (c) Bounding box estimation.

Hough transform, the estimated scoring area may present differently as illustrated by the green circles in Fig. 2d.

However, the proposed strategy comes with an inevitable limitation that is prone to any computer vision task, occlusion. For instance, Fig. 8 shows a scenario where an arrow is heavily occluded as indicated in Fig. 8a, showing resulted in a false arrow detection and localization, where the detected position is at score 9, approximately $10\,\mathrm{deg}$ clockwise from west and the true position is at score 9, approximately $45\,\mathrm{deg}$ clockwise from east. By inspecting the session instance, Fig. 8b shows the residual from image subtraction and it is observed that the image changes are very minimal due to the fading features. Consequently, the Hough transform missed the line detection due to insensitivity as illustrated in Fig. 8c and Fig. 8d.

IV. Conclusion

A two-stage computer vision assisted automatic scoreboard scoring system is proposed in this paper to automatically detect arrows and scoring using camera. During the initiation stage, four vertices of the target face and bull's eye radius are defined using image annotation tool. Next, the target rings are extracted to obtain scoring areas of the target board. In contrast to existing approaches that implement Hough transform for circle detection, this work proposes curve interpolation and convex hull for target ring estimation. This resulted in closer estimation of the true target ring compared to existing approaches and less susceptible to the presence of noise. In the subsequent stage, the operation stage uses two consecutive frames to perform arrow detection and localization by implementing a series of image processing comprising Gaussian blur, image subtraction, binary thresholding, morphology, and Hough transform on probabilistic line detection. The proposed system is evaluated and achieved desired results on a challenging archery session, where the input image is highly skewed and target face is heavily used. However, the system can still produce a false arrow detection when an arrow is severely occluded. This issue can be solved by placing the camera viewpoint tangent to the target face. Alternatively, multi-viewpoint for the target face can be incorporated to prevent occlusion, thus increasing the likelihood of arrow detection and localization.

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