Image processing and computer vision

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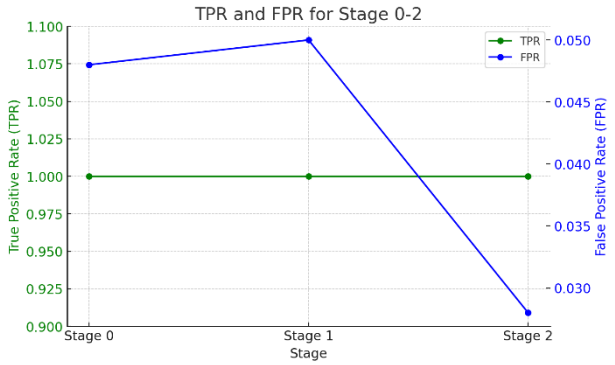
1. sub-task1: Voila-Johns Object Detector

1.1 Training Performance

In the training performance analysis, the classifier demonstrates an ideal TPR of 1 across all stages, indicating complete recognition of positive samples. The FPR, however, shows a significant decrease from the initial stage to the last, dropping from 0.048 to 0.028. This reduction suggests that the classifier is progressively improving at distinguishing between positive and negative samples as more features are introduced at each stage. The consistent TPR and the declining trend in FPR imply that the classifier is becoming more precise in its predictions, reducing the likelihood of false alarms while maintaining a perfect detection rate of actual positives.



1.2Testing Performance

In sub-task 1, my objective was to adjust the parameters in detectMultiScale function to ensure that the TPR for each image is close to 1. This approach resulted, as showed in Figure 1 and 3, resulted in some false positives, the rationale for which will be elaborated in sub-task 2 and 3. According to the data in the Table 1, it's evident that the TPR for the majority of the images is 1. The reason for the differing TPR values compared to the training stage is that the training images, specifically 'dart.bmp', are different from those used in the detection phase. This leads to variations in the TPR. Factors such as differences in background or dartboard appearance between these sets of images can impact the model's performance.

Figure 1: dart1

Figure 2: dart15

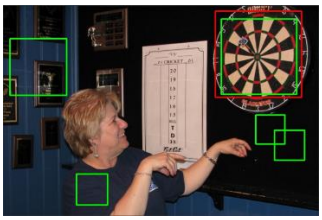


Figure 3: dart0

File Name	TPR	F1
dart0.jpg	1.00	0.33
dart1.jpg	1.00	0.40
dart2.jpg	1.00	0.33
dart3.jpg	1.00	0.29
dart4.jpg	1.00	0.33
dart5.jpg	1.00	0.33
dart6.jpg	1.00	0.40
dart7.jpg	1.00	0.18
dart8.jpg	1.00	0.24
dart9.jpg	1.00	0.25
dart10.jpg	0.67	0.29
dart11.jpg	1.00	0.33
dart12.jpg	1.00	0.67
dart13.jpg	1.00	0.25
dart14.jpg	1.00	0.16
dart15.jpg	1.00	1.00
average	0.98	0.36

Table 1: TPR and F1 score

2. sub-task2: Integration with Shape Detectors

2.1 Hough Details

Figure 4 and Figure 5 shows the optimized magnitude by using NMS and Hysteresis thresholding (details will be provided in task 3), and Figure 6 and Figure 7 displays the results of circle detection within Viola-Jones boxes. For Figure 8, since the Hough Transform is applied locally (reason will be elaborated in 2.3), in Dart13 there are six Hough space images corresponding to six green boxes; I only showcase the central one which is containing the dartboard. Figure 9 and Figure 10 are the final result after removing the green boxes, as we consider the Hough Circle detection as the final outcome.

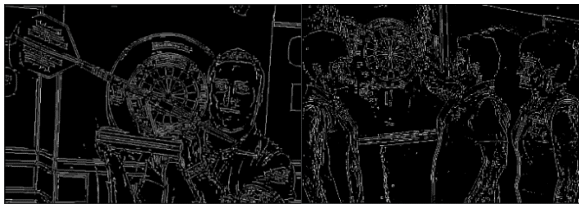


Figure 4: Dart13 Magnitude

Figure 5: Dart15 Magnitude

Figure 6: Dart13 detection

Figure 7: Dart15 detection

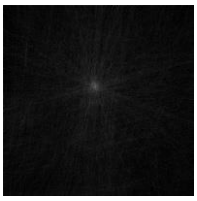


Figure 8: Dart13 middle area Hough2D

Figure 9: Dart13 Final result

Figure 10: Dart15 Final result

2.2 Evaluation

Table 2 presents the TPR and F1 results detected in this phase, along with their improvements relative to Task 1. It is evident that the F1 score has increased for almost every image, with a significant rise in the average F1 score. This indicates a substantial reduction in false positives, while also achieving a TPR of 1 for all. The increase in TPR in Task 2 is primarily due to the refined detection approach, where Hough Circle bounding boxes were used for final results. This change resulted in smaller, more accurate detection areas than in Task 1, leading to better IOU with the ground truth and consequently, a higher TPR. However, there are still some shortcomings, such as the presence of false positives in certain images.

File Name	TPR	ΔTPR	F1	ΔF1
dart0.jpg	1.00	0.00	0.67	0.34
dart1.jpg	1.00	0.00	1.00	0.60
dart2.jpg	1.00	0.00	0.67	0.34
dart3.jpg	1.00	0.00	0.33	0.04
dart4.jpg	1.00	0.00	0.67	0.34
dart5.jpg	1.00	0.00	0.67	0.34
dart6.jpg	1.00	0.00	0.67	0.27
dart7.jpg	1.00	0.00	0.50	0.32
dart8.jpg	1.00	0.00	0.31	0.07
dart9.jpg	1.00	0.00	0.40	0.15
dart10.jpg	1.00	0.33	0.86	0.57
dart11.jpg	1.00	0.00	0.67	0.34
dart12.jpg	1.00	0.00	1.00	0.33
dart13.jpg	1.00	0.00	1.00	0.75
dart14.jpg	1.00	0.00	0.27	0.11
dart15.jpg	1.00	0.00	1.00	0.00
average	1.00	0.02	0.67	0.31

Table 2: TPR and F1 score

2.3 Detection Pipeline

My goal is to reduce false positives and improve the F1 score. My method is applying the Hough Circle Transform within all green boxes detected in task1. I then use only the Hough results as my final detections. This method is correct because in task1 I already make sure that most TPR values equal 1. And this method is also very fast because I use Hough transform in specific areas.

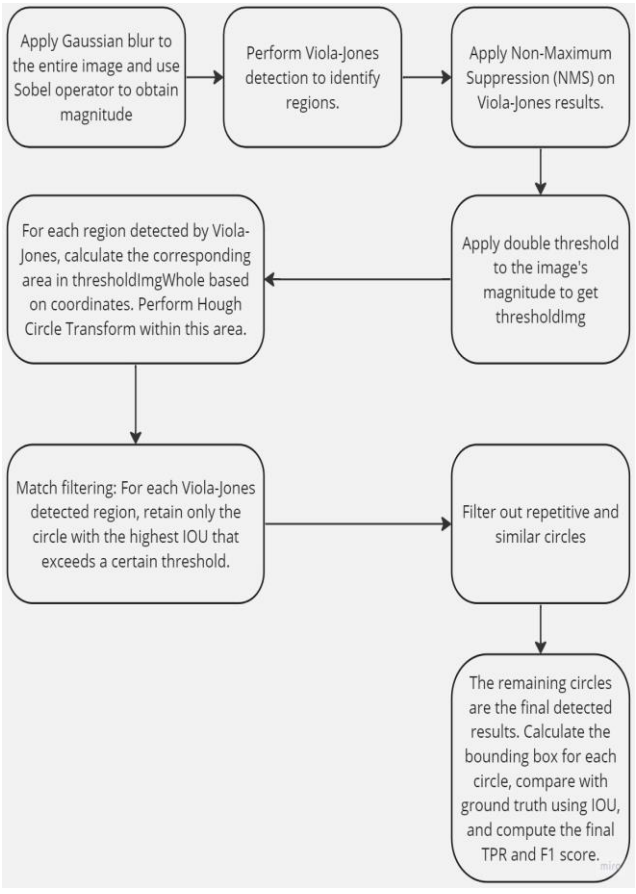


Figure11: Implement flow chart

3. sub-task3: Improving Detector

3.1 Idea

1.To further enhance detection, for each detected circle, I applied the Hough line transform within its area and discarded circles that did not meet a threshold of converging lines.

2. I applied Non-Maximum Suppression (NMS) to the regions detected by the Viola-Jones algorithm to prevent multiple detections of the same area.

3. During magnitude calculation with the Sobel operator, I used a form of NMS that retains only one point when gradients are similar in proximity. This method sharpens edges, avoids thick borders, and reduces unnecessary points, thus speeding up the process.

4. Before using Hough Transform, I applied a Hysteresis thresholding to the magnitude to clearly distinguish between strong and weak edges, retaining only the strong ones.

5. I slightly expanded each green detection area from Viola-Jones detections before applying Hough Transform, accounting for instances where the detected area might not encompass the entire dartboard, leading to missed detections.

6. After obtaining circles from each area, I performed a match filtering between the detected circles and Viola-Jones boxes, retaining only the circle with the maximum IOU for each box, with a limit of one circle per box. This effectively prevented multiple circle detections within a single Viola-Jones box.

7. I filtered global circles to remove similar ones according to IOU, prioritizing larger circles and retaining them in cases of overlapping circles (IOU below the filtering threshold).

Methods 2-7, previously applied in 'task2.py', are complemented by the addition of Method 1 in 'task3.py'.

3.2 Visualise and Comparison

Pictures on the left are the results from task2

Pictures on the right are the results from task3


Figure12: task2_dart6_resutlt Figure13: task3_dart6_resutlt


Figure14: task2_dart3_resutlt Figure15: task3_dart3_resutlt


Figure16: task2_dart5_resutlt Figure17: task3_dart5_resutlt

3.3 Evaluation

This Hough line transform optimization raised the average F1 score to 82%. However, the additional use of Hough Line Transform also substantially increased the run time to around 20 minutes.

File Name	TPR	ΔTPR	F1	ΔF1
dart0.jpg	1.00	0.00	0.67	0.00
dart1.jpg	1.00	0.00	1.00	0.00
dart2.jpg	1.00	0.00	1.00	0.33
dart3.jpg	1.00	0.00	1.00	0.67
dart4.jpg	1.00	0.00	0.67	0.00
dart5.jpg	1.00	0.00	1.00	0.33
dart6.jpg	1.00	0.00	1.00	0.33
dart7.jpg	1.00	0.00	0.67	0.17
dart8.jpg	1.00	0.00	0.40	0.09
dart9.jpg	1.00	0.00	0.40	0.00
dart10.jpg	1.00	0.00	1.00	0.14
dart11.jpg	1.00	0.00	1.00	0.33
dart12.jpg	1.00	0.00	1.00	0.00
dart13.jpg	1.00	0.00	1.00	0.00
dart14.jpg	1.00	0.00	0.33	0.06
dart15.jpg	1.00	0.00	1.00	0.00
average	1.00	0.00	0.82	0.15

Table 3: TPR and F1 score

3.4 Further improvements

1.Optimize the Hough Line Transform to reduce unnecessary computations and improve running time.

2.Develop a Hough Ellipse Transform, which might yield better results for some certain images.