The No Entry Sign Challenge Coursework

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1 The Viola-Jones Object Detector

1.1 Ground Truth and Visualisation

Figure 1 - Images 1, 2, 4, 5, 7 and 11 annotated with red boxes (ground truth) and green boxes (detected faces) after testing the Viola-Jones face detector.

In order to set the ground truth for each image, I manually recorded the rectangle data and stored them in CSV files to be parsed at runtime. My approach to choosing which regions corresponded to 'frontal faces' was that the region must contain a clearly visible human-like face with two eyes, a nose and a mouth. By these criteria, image 5 contains a face in the graffiti (human-like) and the man's face in image 11 is not considered since his facial features are not 'clearly visible'. I set the dimensions of each rectangle such that the chin, forehead and sides of the face are only just included within the region.

1.2 IOU, TPR, F1-Score

Image	TPR	F1-Score
0	NaN	NaN
1	1.000	0.286
2	0.000	0.000
3	NaN	NaN
4	0.333	0.190
5	1.000	0.500
6	NaN	NaN
7	0.500	0.250
8	NaN	NaN
9	NaN	NaN
10	NaN	NaN
11	0.000	0.000
12	0.000	0.000
13	NaN	NaN
14	NaN	NaN
15	NaN	NaN

Table 1 - TPR and F1-Score of the trained Viola-Jones face detector on the sample images.

I calculated the intersection over union (IOU) between each red and green bounding box. Those with an IOU > 0.5 were considered to belong to the true positive (TP) set. I then calculated the true positive rate (TPR) using the following formula:

$$TPR = \frac{Number\ of\ true\ positives}{Number\ of\ 'ground\ truth'\ faces}$$

There are some practical difficulties in assessing the TPR meaningfully. Most notably, images that contain no faces in the ground truth fail to produce a TPR—indicated by 'NaN' in Table 1—due to division by zero. The TPR is not a perfect metric for evaluating the detector's success since it fails to capture information on the number of 'non-face' detections.

An extreme example of this problem is illustrated by a brute force detection algorithm that selects every possible rectangular area within an image as being a 'frontal face'. This algorithm ensures that it is always possible to achieve a TPR of 100% in any detection task. However, this renders the TPR meaningless due to the high false positive rate (FPR).

The F1-Score is an alternative metric that captures both the TPR and FPR, improving our method of evaluating the detector.

2 Building and Testing your own Detector

2.1 Training Performance

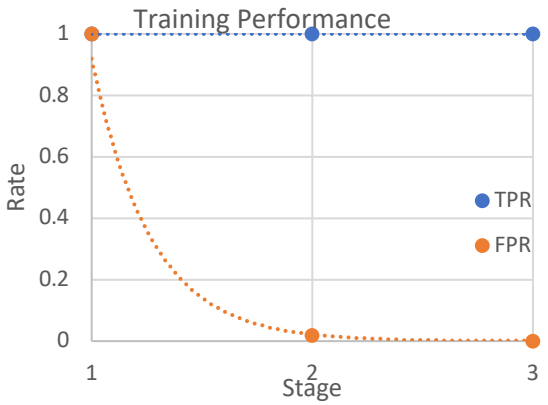

Figure 2 - Performance of the 'no entry' sign classifier at each stage of the training process.

I trained a Viola-Jones classifier to detect 'no entry' signs using OpenCV's Cascade Classifier Training application. As shown in Figure 2, both the TPR and FPR of the classifier had a value of 1.0 after the first stage. This means that the classifier detected everything in an image as being a 'no entry' sign (ground truth signs as well as all 'non-signs').

This improved dramatically with each subsequent stage. By the final stage, the TPR retained its value of 1.0 (i.e., successfully detecting all 'no entry' signs) while the FPR dropped to 0.00055356, suggesting a very low probability of incorrectly identifying an object as a 'no entry' sign.

2.2 Testing Performance

Figure 3 - Images 0, 3 and 12 annotated with red boxes (ground truth) and green boxes (detected signs) after testing using the trained Viola-Jones sign detector.

Image	TPR	F1-Score
0	0.500	0.154
1	1.000	0.400
2	1.000	0.333
3	0.500	0.286
4	0.000	0.000
5	0.000	0.000
6	0.000	0.000
7	0.000	0.000
8	0.333	0.500
9	0.500	0.250
10	0.667	0.667
11	0.000	0.000
12	0.143	0.167
13	0.000	0.000
14	0.000	0.000
15	1.000	0.800
Average	0.353	0.222

Table 2 - Performance of the trained Viola-Jones 'no entry' sign detector, measured using TPR and F1-Score.

The overall performance of the trained Viola-Jones detector on the given images is quite poor. The F1-Score is low due to the large number of false positives. The images in Figure 3 give strong insight into the reason for this. Every detected 'non-sign' is a region that contains a horizontal bar in the middle of its rectangle. Since 'no entry' signs have so few identifiable features, it is highly likely that other objects containing the same, simple bar will get detected.

The TPR is also much lower than during training. One possible reason for this is that the classifier was just trained on variations of the same original image. Some of the 'no entry' signs in the testing images may differ from any of the generated training samples due to factors such as lighting conditions, occlusion and orientation.

Another obvious reason is that the *minSize* parameter to the detector was set to 50x50, preventing signs smaller than this from being detected. I modified this parameter in order to be able to capture the smaller signs. Although this improved the average TPR to 0.466, its false positive rate drastically increased. I opted to leave the *minSize* parameter as 50x50 and use other methods to detect smaller signs instead.

3 Integration with Shape Detectors

3.1 Hough Details

Figure 4 - Visualisations for sign detection on images 2 (left column) and 3 (right column). Rows correspond to thresholded gradient magnitudes, circle Hough space and annotated images with red boxes (ground truth) and green boxes (detected signs).

3.2 Evaluation

Image	TPR	F1-Score	±TPR	±F1-Score
0	0.500	0.667	+0.000	+0.513
1	1.000	1.000	+0.000	+0.600
2	1.000	1.000	+0.000	+0.667
3	0.500	0.500	+0.000	+0.214
4	0.000	NaN	+0.000	NaN
5	0.000	NaN	+0.000	NaN
6	0.000	NaN	+0.000	NaN
7	0.000	NaN	+0.000	NaN
8	0.167	0.286	-0.166	-0.214
9	0.500	0.667	+0.000	+0.417
10	0.667	0.667	+0.000	+0.000
11	0.000	NaN	+0.000	NaN
12	0.143	0.250	+0.000	+0.083
13	0.000	NaN	+0.000	NaN
14	0.000	NaN	+0.000	NaN
15	0.500	0.667	-0.500	-0.133
Average	0.311	0.634	-0.042	+0.239

Table 3 - Performance of the Viola-Jones detector combined with the Hough circle detector. The final two rightmost columns tabulate the difference between the values compared with the Viola-Jones-only detector.

Key merits:

- Almost all false positives were eliminated
- The F1-Score increased

Key shortcomings:

- It detected round blue signs that contained a bar
- Some actual signs that were detected by Viola-Jones but not the Hough transform were no longer detected
- The TPR decreased slightly because of this

3.3 Detection Pipeline

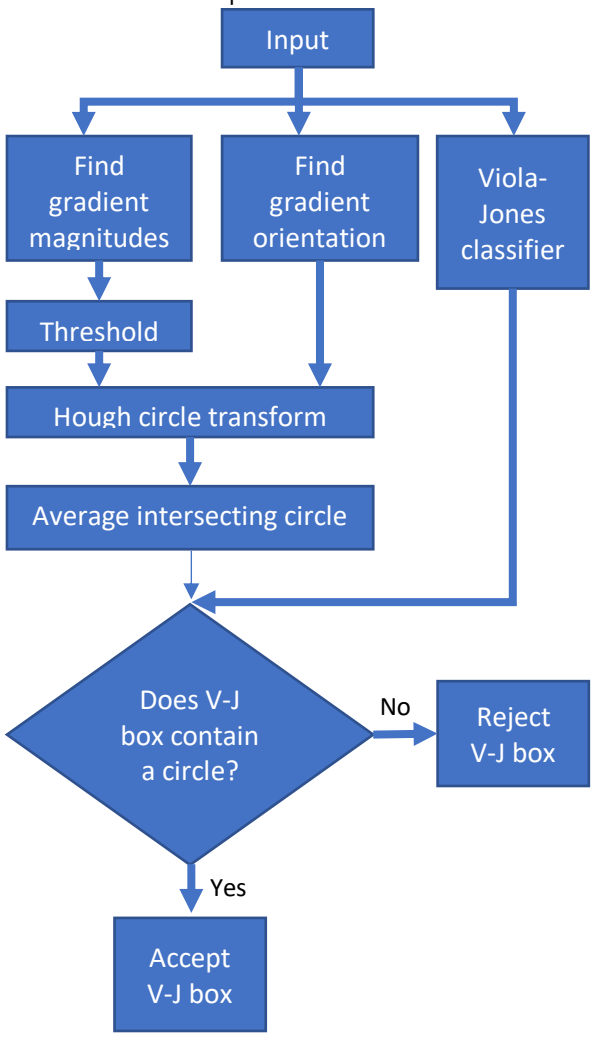

Figure 5 - Pipeline for detecting a 'no entry' sign using Viola-Jones combined with the circle Hough transform.

Rationale:

- By itself, the Viola-Jones detector failed to detect some signs and made many false detections
- Although I attempted to implement the line Hough transform, it wasn't effective enough
- I felt that detecting circles alone wouldn't be enough to confidently detect new regions
- Instead, I opted to use Hough circle transform to 'filter out' the false positives produced by Viola-Jones

4 Improving your Detector

4.1 Idea

- My Viola-Jones + circle Hough Transform did a great job at reducing false positives
- The only exception being blue signs that contained bars
- I decided to analyse the colour of a chosen Viola-Jones box for an acceptable red-white pixel ratio in order to combat this
- I also decided to use this method in conjunction with circle-only detections as a way of detecting new regions

4.2 Visualisation

Figure 6 - Images 3 (top) and 14 (bottom) annotated with red boxes (ground truth) and green boxes (detected signs). The left column shows the result from the previous VJ + circles detector and the right column shows the final detector including colour analysis.

4.3 Evaluation

Image	TPR	F1-Score	±TPR	±F1-Score
0	0.500	0.667	+0.000	+0.000
1	1.00	1.000	+0.000	+0.000
2	1.000	1.000	+0.000	+0.000
3	0.500	0.667	+0.000	+0.167
4	1.000	0.800	+1.000	NaN
5	1.000	0.182	+1.000	NaN
6	0.500	0.667	+0.500	NaN
7	0.000	0.000	+0.000	NaN
8	0.333	0.500	+0.166	+0.214
9	0.500	0.667	+0.000	+0.000
10	0.667	0.800	+0.000	+0.133
11	1.000	1.000	+1.000	NaN
12	0.286	0.444	+0.143	+0.194
13	0.000	NaN	+0.000	NaN
14	1.000	1.000	+1.000	NaN
15	0.500	0.667	+0.000	+0.000
Average	0.612	0.671	+0.301	+0.037

Table 4 - Performance values of the final detector. The rightmost two columns compare the values of the final detector with those of the V-J + circles detector.

Key merits:

- Significantly increased TPR and F1-Score when compared to the previous approaches
- Almost zero false positives
- No longer detects round blue signs that contain horizontal bars
- Detects some smaller signs that were previously impossible to detect with the Viola-Jones detector

Key shortcomings:

- Starts detecting some faces as signs (since it sees them as circles with a good red-white pixel ratio)
- Still doesn't detect all actual signs