COMS30121 - Image Processing and Computer Vision (2019-20)

Assignment Weeks 6-10 (pair programming work, summative, 50%)
The Dartboard Challenge

Overview: This assignment is the summative piece of unit coursework for COMS30121 only focusing on classical computer vision algorithms for object and shape detection. It runs over approximately 4 weeks. The coursework is worth 50% of the unit mark. It is to be completed in your programming teams of two, which are registered and agreed as published on the unit website. Team changes are not permitted. Please report any team issues before you start work on this assignment.

Submission: Each student is required to upload their full piece of work (incl all source code files, and your PDF team report) as a single ZIP file to Blackboard under the submission point "Image Processing & Computer Vision CW" before the ***deadline at 17:59 on Monday 2nd December 2019.*** Make sure you submit it an hour early or so (not last minute!) to avoid upload problems. Even if your upload is a single second late you will immediately have 10% deducted (per day) from your mark by the system (out of our control). ***Each team member*** has to upload an identical copy of the zip file containing the team's work.

Assessment: You will be marked on your code, report and a brief viva-style presentation of your work. Both team members should understand all of the code written and must be present for the final presentation. During the presentation we will run and discuss the submitted program. The presentation sessions are to be scheduled in weeks 10, 11 and 12 and we will publish the exact times when each team presents on the unit website. All the team members have to attend their presentation slot to get a mark. At your presentation, we will ask you questions about your work, give you feedback and you will be able to showcase your work's merit. Do not attempt to plagiarise, copy code between teams etc. We will ask you intricate questions about your work and code in the presentation. Apart from the Hough transform functions, you are allowed to use any of OpenCV's functionality – but, in any case, all the team **must** understand the algorithmic workings of the used functions.

Time Management: You should be able to work your way through the task in not more than approximately 18h per person including lab slots. For instance, subtask one should take you no more than a 2h lab session, subtask two should take you less than 3h, and task three should take not much more than approx. 10h given your existing, formative work on the subject which you are allowed to use and develop further in this assignment. If you find your team requires significantly more time than suggested or struggles then please flag this early and make sure you seek help in labs and forum.

Task Overview: Detecting Dart Boards

Introduction. Detecting (locating & classifying) instances of an object class in images is an important application in computer vision as well as an ongoing area of research. This assignment requires you 1) to experiment with the classical Viola-Jones object detection framework as discussed in the lectures and provided by OpenCV, and 2) to combine it with other detection approaches to improve its efficacy. Your approach is to be tested and evaluated on a small image set that depicts aspects of a popular sport and pasttime – darts.

Basic Task Structure: The task runs over approximately 4-5 weeks. It consists of four subtasks which incrementally build upon each other:

- ***First Subtask* (up to max 10 marks)**: This introductory part will ask you to run and understand the usage of the Viola-Jones detector as provided by OpenCV. In particular, you will experiment with the pre-built off-the-shelf frontal face detector and apply it so some example images. This part lets you gain experience on how and how well this classical detection framework can operate in practice.

- ***Second Subtask* (up to max 20 marks):** In this second task you will build your own object detector by training the Viola-Jones framework on a customised object class, that is `dartboards'. You will then test the detector's performance and interpret your results on an image set. This part lets you gain experience on how to train and evaluate the Viola Jones framework in practice.

- ***Third Subtask* (up to max 35 marks):** In this subtask you will combine your detector with **your own implementation** of the Hough transform to detect component configurations of the dartboard shape in order to improve detection performance. (Do not use OpenCV's implementations of the Hough transform!) It is up to you to decide if you opt to implement the Hough transform for lines, circles, ellipses, your own parameterized shape or the generalised Hough transform or combinations of them for this task. This task will test your engineering skills of practically applying taught concepts and integrating them within an application context.

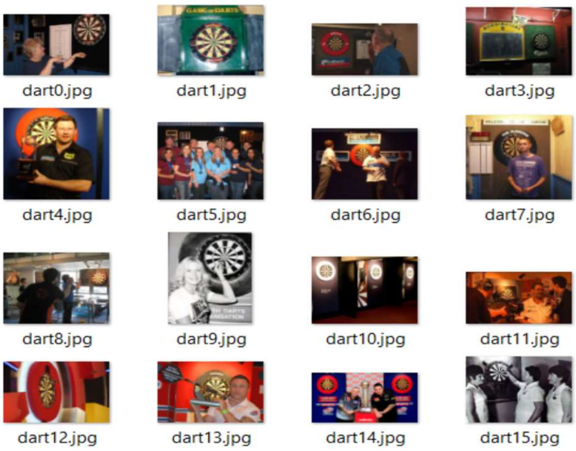
- ***Fourth Subtask* (up to max 10 marks):** In order to be able to reach marks close to and above the first class boundary, we ask you to research, understand and use in OpenCV at least one other appropriate vision approach to further improve the detection efficacy and/or efficiency of the system.

The ***final 25 marks for this coursework*** are reserved for excellence throughout your work, how well you inform your development on evidence and evaluation, and how well you comprehend the techniques used. Here we look for an outstanding understanding, concise presentation, excellent write-up and clean implementation. For significant marks in this category it should become clear during the presentation that a student has reached a level of understanding that allows for contextualisation and reflection well beyond the taught content. Very high marks in this category are reserved for work that is novel and publishable in principle.

(Note that students within a team may receive different grades dependent on their understanding of the work and/or signed off contribution weights as explained at the end of the task.)

Subtask 1: The Viola-Jones Object Detector

You are given some first sample code in the file **face.cpp** and 16 real-world images called **dart0.jpg** to **dart15.jpg**:



First, understand, compile and build the provided **face.cpp** source program to generate an executable. (You may need to adjust include paths if you use your own machine). On lab machines you would compile and build the provided file like this providing all parameters in one single line:

g++ face.cpp /usr/lib64/libopencv_core.so.2.4
/usr/lib64/libopencv_highgui.so.2.4
/usr/lib64/libopencv_imgproc.so.2.4
/usr/lib64/libopencv_objdetect.so.2.4

Make sure the built program reads the provided XML file **frontalface.xml,** which contains a strong classifier trained using AdaBoost for detecting frontal human faces. The program also expects the name of an example image file to which it applies the classifier. For instance, given the image **dart4.jpg** and the file **frontalface.xml** in the directory where you built and run your program in, you can run your compiled and built program as follows:

./a.out dart4.jpg

The program outputs the number of faces found to the console and the resulting detections are finally visualised in the produced output image called **detected.jpg**.

The First Page of your Report (strict limit):

a) ***GROUND TRUTH AND VISUALISATION:*** Manually annotate all the test images and generate ground truth in form of bounding box (x,y,width,height) coordinates for all valid frontal faces and store these annotations (e.g. in a file or array). Then test the detector's performance (with the given parameters as provided by **face.cpp**) on five given example images: **dart4.jpg, dart5.jpg, dart13.jpg, dart14.jpg** and **dart15.jpg**. Produce the five result images with bounding boxes of the ground truth (in red) and actually detected instances (in green) drawn around frontal faces and include them in your report.

b) ***IOU, TPR, F1-SCORE:*** Implement some code using a manually fixed threshold on the IntersectionOverUnion (IOU) between bounding boxes to judge which faces given the ground truth were successfully detected. Calculate and note in your report in table form the TPR (true positive rate) for all test images**,** that is the fraction of successfully detected faces out of all valid faces in an image. Discuss in your team and briefly note in your report 1) some practical difficulties in assessing the TPR meaningfully, 2) why it is always possible to achieve a TPR of 100% on any detection task, and 3) implement a small piece of code to calculate the F1-score of your face detection system accurately and meaningfully for all test images given the ground truth and include it as a table in the report.

Subtask 2: Building & Testing your own Detector

The second subtask requires you to build an object detector that recognises dartboards. The initial steps of this subtask introduce you to OpenCV's boosting tool, which you can use to construct an object detector that utilises Haar-like features.

In order to give you a smooth start you are provided with readily compiled versions of two OpenCV tools you can use to build your object detector: **opencv_createsamples** and **opencv_traincascade**. (These binaries are part of all standard OpenCV installations.) You are also given **dart.bmp** containing a dartboard that can serve as a prototype for generating a whole set of positive training images.

In addition, a large set of negative images (containing no dart boards) is provided in a directory called **`negatives'** and a text file **negatives.dat** listing all filenames in the directory.

dart.bmp

First, create your positive training data set of 500 dartboard samples from the single prototype image provided. To do this, you can run the tool **opencv_createsamples** via the following single command if you use lab machines and execute it in a folder that contains the **negatives.dat** file, the **dart.bmp** image and the **negatives** folder:

./opencv_createsamples -img dart.bmp -vec dart.vec
-w 20 -h 20 -num 500
-maxidev 80 -maxxangle 0.8 -maxyangle 0.8 -maxzangle 0.2

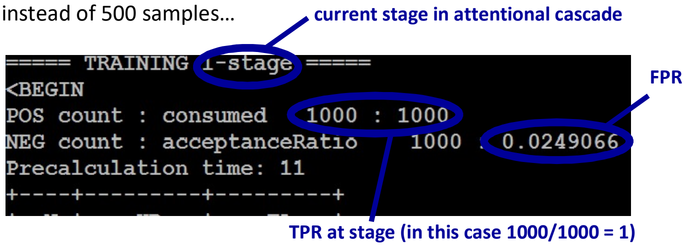
This will create 500 tiny 20×20 images of dart boards (later used as positive training samples) and create the file **dart.vec**, which contains all these 500 small sample images. Each of the sample images is created by randomly changing viewing angle and contrast (up to the maximum values specified) to reflect the possible variability of viewing parameters in real images better.

Now use the created positive image set to train a dartboard detector via AdaBoost. To do this, create a directory called **dartcascade** in your working directory. Then run the **opencv_traincascade** tool with the following parameters as a single command in your working directory:

./opencv_traincascade -data dartcascade -vec dart.vec
-bg negatives.dat -numPos 500 -numNeg 500 -numStages 3
-maxDepth 1 -w 20 -h 20 -minHitRate 0.999
-maxFalseAlarmRate 0.05 -mode ALL

This will start the boosting procedure and construct a strong classifier stored in the file **cascade.xml,** which you can load in an OpenCV program for later detection as done in Subtask 1 of the assignment.

During boosting the tool will provide updates about the machine learning in progress. Here is an example output when using 1000 instead of 500 samples…



The boosting procedure considers all the positive images and employs sampled patches from the negative images to learn. The detector window will be 20×20. To speed up the detection process, the strong classifier is built in 3 parts (numStages) to form an attentional cascade as discussed in the Viola-Jones paper. The training procedure may take up to 15min for reasons discussed in the lectures – stop the training and restart if it exceeds this time.

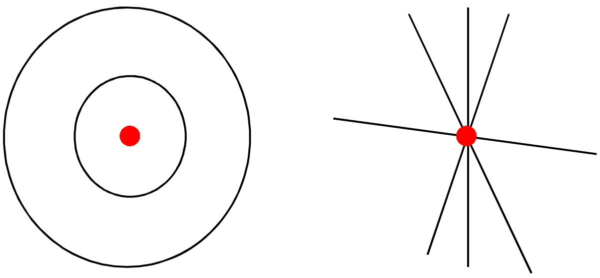
The Second Page of your Report (strict limit):

a) ***TRAINING PERFORMANCE:*** The training tool produces a strong classifier in stages. Per stage the tool adds further features to the classifier and prints the achieved TPR and FPR (false positive rate) for that point on the training data (see Figure). Collate this information into a graph that plots TPR vs FPR on the training data for the three different stages. Produce this graph in your report and briefly interpret what it shows.

b) ***TESTING PERFORMANCE:*** Test the dartboard detector's performance on all given example images. Produce the result images with bounding boxes drawn around detected dartboard candidates (in green) and ground truth (in red) and include 3 of them in your report. In tabular form, calculate the overall TPR and F1 score per image and the average of these scores across the 16 images. Briefly discuss the performance achieved and give reasons for the different TPR values compared to the performance achieved in a).

Subtask 3: Integration with Shape Detectors

For the third subtask, use at least one Hough Transform on the query images in order to detect important shape configurations of dartboards. Feel free to use and/or adapt your implementation of the Hough Transform from former formative tasks. You must implement your own Hough transform(s). Utilize the information (e.g. on lines, circles, ellipses) to aid dartboard detection. For instance your system could consider the center of concentric circles or ellipses, and points where multiple line segments intersect:



Think carefully how to combine this new evidence with the output of your Viola-Jones detector in order to improve on results. Implement and evaluate this improved detector.

The Third Page of your Report (strict limit):

a) ***HOUGH DETAILS:*** Show in your report for two of the given example dart images which best exhibit the merit and limitations of your implementation: 1) the thresholded gradient magnitude image used as input to the Hough Transform, 2) a 2D representation of the Hough Space(s), 3) the result images showing final detections using bounding boxes (in green) and the ground truth (in red).

b) ***EVALUATION:*** Evaluate your detector on all of the example images. Provide the TPR and F1-score for each of the test images and their average across the 16 images in a table. Note in extra table columns the difference w.r.t. to the detection performances using only the Viola-Jones detector. Briefly note in bullet points the key merits and shortcomings of your now enhanced implementation.

c) ***DETECTION PIPELINE:*** In a flow diagram, depict how you have combined evidence from the Hough Transform(s) and Viola-Jones detector. In bullet points, explain briefly your rationale behind the way you have combined evidence.

Subtask 4: Improving your Detector

The final subtask allows you to develop the dartboard detector further into a direction you choose. We ask you to identify and utilise some image aspects/features able to improve detection results further. This will generally include identifying, researching, understanding and using in OpenCV one other appropriate vision approach to further improve the detection efficacy and/or efficiency.

The Forth Page of your Report (strict limit):

a) ***IDEA:*** In bullet points, explain briefly your rationale behind selecting the approach you have taken.

b) ***VISUALISE:*** Visualise important aspects of your technique in two of the given example dart images selected to best exhibit the merit of your approach.

c) ***EVALUATE:*** Evaluate your final detector on all of the example images, show the improvements in TPR and F1-score compared to previous approaches. Briefly note in bullet points the key merits and shortcomings of your final implementation.

d) ***SIGN OFF:*** Finally, each team partner has to sign the report (either physically and scan it or digitally) and thereby confirm that they agree with a provided contribution weight for each of the two team members (out of 2 overall). For example, MemberX = 1.1, MemberY = 0.9; or for equal contributions: MemberX = 1, MemberY = 1. (Organise your work so contributions are approximately equal and report to the unit lecturers early in case of team member disconnects.)

Program Structure for Submission

We ask you to submit a zip file to Blackboard before the deadline. The file should contain all your team's source code and your PDF report, if needed include a readme.txt to explain how to compile/built. Your final detector program will be presented in your scheduled presentation and should take one parameter, that is the input image filename, and produce at least an image **detected.jpg**, which highlights detected dartboards by bounding boxes. You can use your own machines or lab machines to develop and present. Make sure you regularly save/backup your work, monitor workload, meet regularly with your team partner and discuss your work together throughout the duration of the project.

MARKING DETAILS

The markers who will look at your work and conduct the interactive presentation of it will arrive at individual marks by making an academic judgement based on: 1) an overall project teamMark in accordance with the mark breakdown in the introduction and judged along the generic marking guidelines corroborated by the team's understanding of the project concepts and implementations, and 2) the signed-off contributions breakdown supplied by the team, and 3) the understanding of the project concepts and implementations as shown by individual students during the presentation. In ordinary cases where teamMark and individualWeights are available and the individualWeight is close to 1 (between 0.8 and 1.2 as it should be in almost all cases) and the understanding of concepts and implementations is similar for both students then the individual mark is derived using the formula teamMark*(1+individualWeight)/2. However, the academic markers have the discretion to differ from this formula and pass final academic judgement in line with the marking criteria in more complex cases where evidence between teamMark, contribution weights, and shown insight during the presentation is inconsistent or contributions differ significantly etc.

GENERIC MARKING GUIDELINES

OUTSTANDING PROJECT (80+)
+ mastery of advanced methods in all aspects;
+ truly impressive outcome, novelty, worthy of dissemination 'as is' under appropriate conditions;
+ synthesis in an original way using ideas from across and beyond the subject;
+ outstanding presentation of work, implementation, report and individual understanding of concepts and implementation;
+ exceptional command of the techniques used with deep critical analysis and reflection;
+ evidence of outstanding individual contributions;

- FIRST CLASS PROJECT (70+)
+ excellent outcome in all aspects;
+ evidence of excellent use and deep understanding of a wide range of techniques;
+ study, originality, and synthesis clearly beyond the bounds of taught approaches;
+ excellent presentation of work, implementation, report and individual understanding of concepts and implementation;
+ excellent command of the techniques used with evidence of critical analysis and reflection;
+ evidence of excellent individual contributions;

- MERIT PROJECT (60+)
+ very good outcome; fully and robustly working solution;
+ evidence of very good use and very good understanding of a range of techniques;
+ study, comprehension, and synthesis beyond the bounds of standard approaches;
+ very good presentation of work, implementation, report and individual understanding of concepts and implementation;
+ evidence of critical analysis and judgement;
+ evidence of productive individual contributions;

- GOOD PROJECT (50+)
+ good outcome;
+ evidence of good use and good understanding of standard techniques;
+ some grasp of issues and concepts underlying the techniques;
+ adequate presentation of work, implementation, report and individual understanding of concepts and implementation;
+ evidence of comprehension and appropriate use of techniques;
+ evidence of positive individual contributions;

- PASSING PROJECT (40+)
+ limited outcome; yet basic, partly working solution;
+ insecure understanding and limited use of basic techniques;
+ limited grasp of issues and concepts underlying the techniques required;
+ existing, but poor presentation of work, implementation, report and/or individual understanding of concepts and implementation;
+ weak comprehension and use of techniques;