CS 415 Mini Project 3

1 Question Answering

Q1. K-means and mean shift are two common clustering algorithms that could be used for segmenting an image. What do you think are their commonalities and differences? (10 pt)

Q2. Suppose you want to cluster five 1D points {0, 1, 2, 3, 4}. You have got 2 initial centroids 3.0 and 4.0 for the K-means algorithm with K=2. Please manually perform two iterations of this K-means algorithm. For each iteration, what you need to calculate is (1) the cluster assignment for each point, and (2) the updated centroids. (10 pt)

Q3. Please describe in your own words (1) the process of using histogram for color segmentation, and (2) the process of using a Gaussian model for color segmentation. Hint: both processes comprise a training stage and a testing stage. (15 pt)

Q4. A 5x5 grayscale image is given below. Compute the Hessian matrix for the 3x3 blue window (*W*). The image gradient can be calculated by finite difference. (15 pt)

1	1	1	1	1
1	1	0	2	1
1	2	2	1	1
1	2	1	0	1
1	1	1	1	1

$$H = \sum_{(x,y)\in W} \begin{bmatrix} I_x(x,y)^2 & I_x(x,y)I_y(x,y) \\ I_x(x,y)I_y(x,y) & I_y(x,y)^2 \end{bmatrix}$$

2. Programming

P1. In our code tutorial for histogram-based color segmentation, the result is not very satisfactory because there is only one training image and it does not capture all the color variations of skins well. You can follow the steps below to improve the performance.

- Collect at least 10 different skin patches from the Internet or your own photo gallery. Collect training data from the testing image is prohibited. (10 pt)
- Modify the code or build your own code from scratch to train a new model (that is, to calculate the HS histogram) on all these patches. Use this new model to segment testing_image.bmp to obtain improved result. (10 pt)

P2. In addition to building a skin color model based on the histogram, an alternative approach is to model the skin color via a 2D Gaussian distribution, with mean μ and covariance matrix ∑. d=2 is the dimension of the random vector.

$$p(\mathbf{x} \mid \mu, \Sigma) = \frac{1}{\sqrt{(2\pi)^d |\Sigma|}} \exp\left(-\frac{1}{2}(\mathbf{x}-\mu)^T \Sigma^{-1} (\mathbf{x}-\mu)\right)$$

- Use the training data collected in P1 to build a Gaussian-based skin color model. What you need to do is to estimate the mean vector and the covariance matrix of the 2D Gaussian distribution[1]. Hint: the Gaussian distribution models continuous random variables, thus color space quantization is not required. (10 pt)
- Calculate the skin probability for each pixel in testing_image.bmp based on the estimated Gaussian distribution and set a threshold to perform segmentation. (15 pt)

Undergraduate students are allowed to use the numpy.cov[2] function to estimate the covariance matrix and use the scipy.stats.multivariate_normal.pdf[3] function to calculate the skin probability of each testing pixel.

P3. Self-study the Harris corner detector[4] implemented in OpenCV and test it on checkerboard.png and toy.png. (5 pt)

3 Submission

Please follow the instructions below for submission.

- You need to upload two files to Blackboard: a PDF file and a .py file[5]. Do not compress them into a single ZIP file.
- The PDF file contains all your solutions to this homework. For Question Answering, you can either type answers or handwrite them and take a photo. For Programming, you need to include output of the program such as a processed image.
- The .py file contains all your code for the programming problems.

[1] Calculate the "sample mean" and "sample covariance matrix": https://en.wikipedia.org/wiki/Estimation_of_covariance_matrices

[2] https://numpy.org/devdocs/reference/generated/numpy.cov.html

[3] https://docs.scipy.org/doc/scipy/reference/generated/scipy.stats.multivariate_normal.html

[4] https://opencv24-python-tutorials.readthedocs.io/en/latest/py_tutorials/py_feature2d/py_features_harris/py_features_harris.html

[5] Using Jupyter Notebook and submitting a .ipynb file instead of a .py file are fine.