ENPM 673 Project 3

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1 Introduction

This project focuses on color segmentation using concepts of Gaussian Mixture Modelling and Expectation Maximization (EM). We are provided with an underwater video sequence consisting of 3 buoys of different colors; yellow, orange, green. Since the buoys have been captured in an underwater scenario, change in lighting intensities and noise make it difficult to employ the use of conventional segmentation techniques involving color thresholding. Hence, we choose to develop a Gaussian Mixture Model that can learn the color distributions of the buoys present in the video and use them for segmentation. The remaining sections of the report discuss about the implementations of the above mentioned concepts.

2 Data Preparation

2.1 Buoy Extraction

1. We extract frames from the given video sequence.
2. From the extracted frames, using getpts function in MATLAB we choose two points pertaining to the buoy namely the center and a point on the boundary of the buoy.
3. Having these 2 points we extract the buoy from the frames. The examples of extracted buoys can be seen below.

Figure 1: Extracted orange, yellow, and green buoys

4. Following the above process we extracted 169 orange buoys, 200 yellow buoys and 43 buoys.
5. We then set 70 % of the extracted buoys pertaining to each class as training data and rest 30 % as testing data.

2.2 Plotting Average Histogram for the extracted buoys

1. Average color histogram for each colored buoy is computed by evaluating the histogram for all extracted buoys pertaining to a color class and then averaging them together.

2. As this project deals with colors such as orange, green, and yellow, we feel operating in the RGB color space is sufficient and hence the histograms are also evaluated for these 3 channels.
3. We split each frame containing the extracted buoys into their corresponding B, G, R channels and count the pixels that do not correspond to the white background.
4. Using the pixel count in each channel, we evaluate the histograms for each frame, and average them all together to obtain the average color histogram.
5. The peaks in the average color histograms to some extent explained its relationship with that of the color class.
6. For an orange buoy, the number of pixels pertaining to red channel were higher than the blue and green channel. But still, in order to enhance detection in degenerate cases such as variation in lighting conditions, and noise, we decided to use both the red and blue (even green could be used) channel to represent an orange buoy.

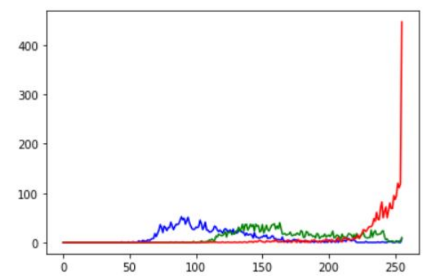

Figure 2: Average Color Histogram of an orange buoy

7. For a green buoy, the peak pertaining to green channel was higher than the blue and red channel. But still, in order to enhance detection in degenerate cases such as variation in lighting conditions, and noise, we decided to use all red, blue, and green channel to represent an orange buoy.

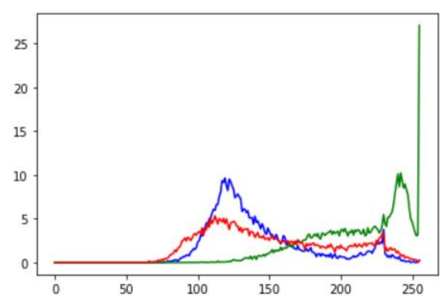

Figure 3: Average Color Histogram of a green buoy

8. For a yellow buoy, the peak about the red and green channels were comparable and significant than the blue channel. But still, in order to enhance detection in degenerate cases such as variation in lighting conditions, and noise, we decided to use all red, blue, and green channel to represent a yellow buoy.

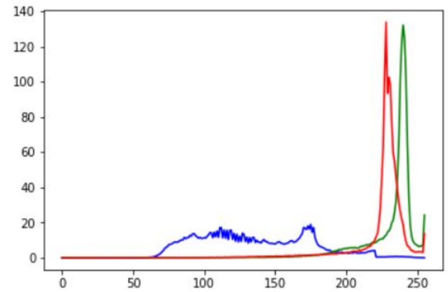

Figure 4: Average Color Histogram of a yellow buoy

3 Gaussian Mixture Models (GMM) and Maximum Likelihood Algorithm

Gaussian Mixture Models are soft clustering models that is comprised of a cluster of Gaussians. It is a probabilistic model that assumes all the data points are generated from a mixture of a finite number of Gaussian distributions with unknown parameters.

The main disadvantage in GMM is that the data is unlabeled, so one cannot determine which point came from which component. Expectation-maximization algorithm solves this problem through iterative process.

Each Gaussian is represented by the following paramters:

- mean μ
- covariance σ
- mixing probability π

The general Gaussian probability density function is given by,

$$N(X|\mu, \sigma) = \frac{1}{(2\pi)^{\frac{D}{2}} \sigma^{\frac{1}{2}}} e^{-\frac{1}{2}(\mathrm{X} - \mu)^{\mathrm{T}} \sigma^{-1} (X - \mu)} \tag{1}$$

Where,

- X represents data points
- D is the number of dimensions

The mixing probabilities also must meet the condition,

$$\sum_{k=1}^{K} \pi_{\mathrm{k}} = 1 \tag{2}$$

Finally, the Gaussian Mixture Model is given by,

$$p(X_{\mathrm{n}}) = \sum_{k=1}^{K} \pi_{\mathrm{k}} N(X_{\mathrm{n}}|\mu_{\mathrm{k}}, \sigma_{\mathrm{k}}) \tag{3}$$

With the above mentioned concepts, we implement ND-Gaussian fitting to segment different colored buoys. From the average color histogram for each channel of different colored buoys, we can decide the number of clusters and dimensions for our Gaussian. Then we finally implement the Expectation-Maximization (EM) algorithm to compute optimal parameters. At first we select random components (i.e., randomly selected center points and a common standard deviations) and compute for each point the probability of being generated by each component of the model. Then we fine tune the parameters i.e., mean and standard deviations of each Gaussian formed for each considered channels. Repeating this process guarantees to always converge to a local optimum values.

3.1 Learning Color Models and Expectation-Maximization (EM) Algorithm

1. For an orange buoy, we consider both red and blue channel. Also, keeping in mind the spread of these 2 channels, we model 2 clusters for each of the 1-Dimensional Gaussian model pertaining to the 2 channels.

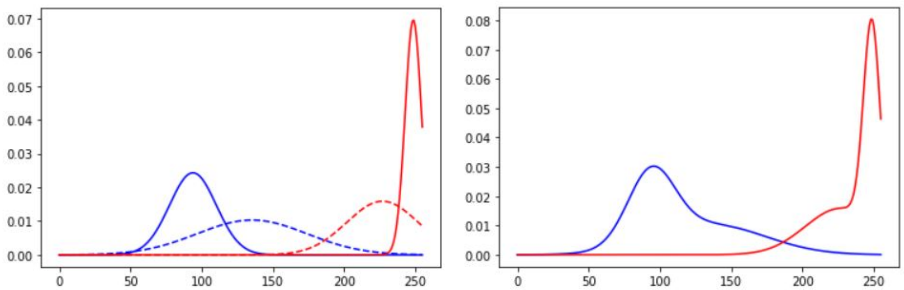

Figure 5: 2 1-Dimensional Gaussian representing an orange buoy

2. For a green buoy, we consider all 3 channels. Also, keeping in mind the spread of these 3 channels, we model 3 clusters for each of the 1-Dimensional Gaussian model pertaining to the 3 channels.

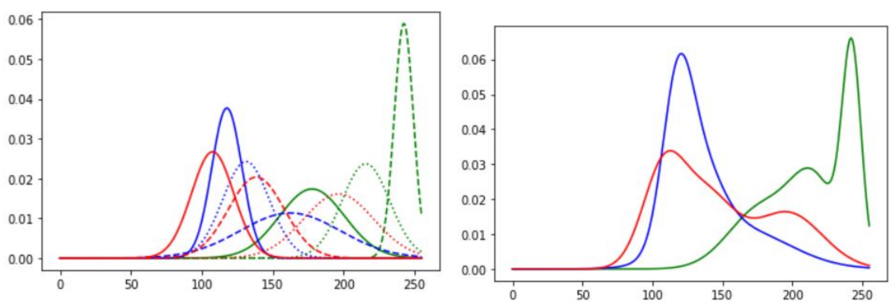

Figure 6: 3 1-Dimensional Gaussian representing a green buoy

3. For a yellow buoy, we consider all 3 channels. Also, keeping in mind the spread of these 3 channels, we model 2 clusters for each of the 1-Dimensional Gaussian model pertaining to the 2 channels.

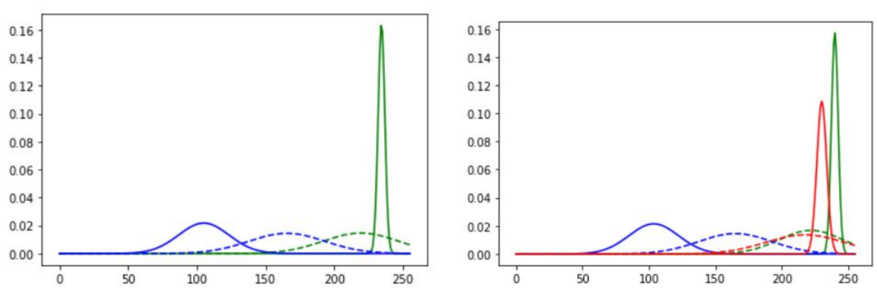

Figure 7: 2 1-Dimensional Gaussian representing a yellow buoy

4. The GMM parameters μ, σ that fits our purpose of segmenting the different colored buoys are estimated using Expectation-Maximization (EM) algorithm.

   - Initialize the N 1-Dimensional Gaussians for each channel with different mean and standard deviations; in case of higher order Gaussian, we initialize mean and covariance. In case of the orange buoy, 2 1-Dimensional Gaussians for each channel. In case of the green buoy, 3 1-Dimensional Gaussians for each channel.

- Using this as the starting point, we then evaluate the new expected probabilities on the training dataset.
- We then evaluate the updated parameters by maximizing the likelihood of the data in a given training dataset.
- The evaluation of expecation and maximization of the likelihood is done iteratively on the dataset.
- The number of iterations can be chosen based on the convergence of the log-likelihood function.

$$\ln N(X|\mu, \sigma) = -\frac{D}{2}\ln 2\pi - \frac{1}{2}\ln \sigma - \frac{1}{2}(X-\mu)^{\mathrm{T}}\sigma^{-1}(X-\mu) \tag{4}$$

4 Buoy Detection

This part of the project is merely a testing phase.

1. The model parameters of the ND-Gaussians obtained during the training phase is used to segment the different colored buoys in the given test video.
2. We then threshold the GMM's to obtain the most probable pixel values that can represent the different colored buoys.
3. cv2.findContours() is used to detect the contours of the segmented buoy, cv2.minEnclosingCircle() is used to find the enclosing circle for the contour, and cv2.cirlce to draw circle on the detected contour.

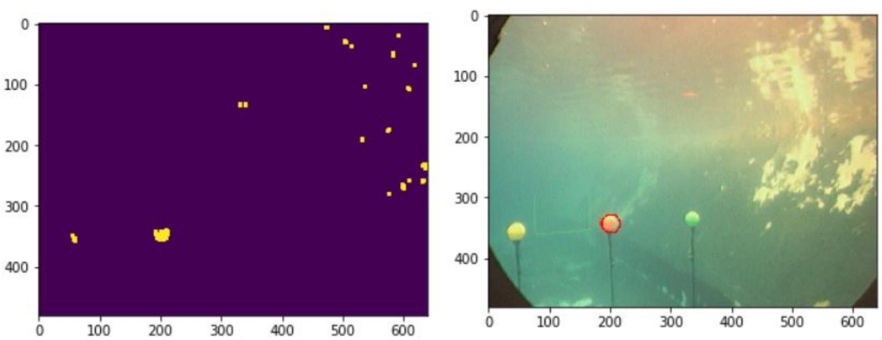

Figure 8: Orange Buoy Segmentation

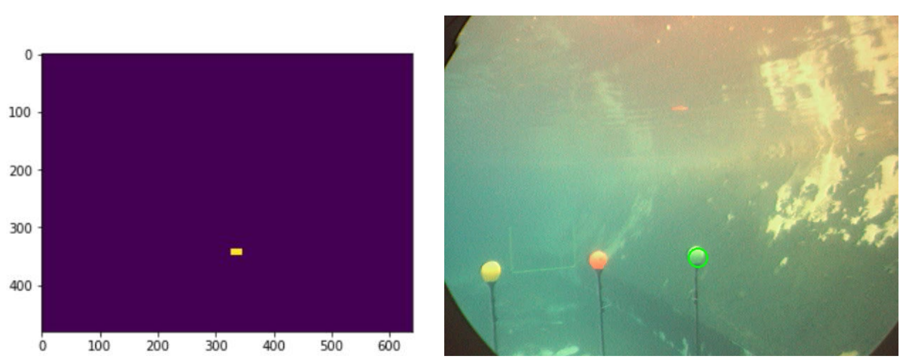

Figure 9: Green Buoy Segmentation

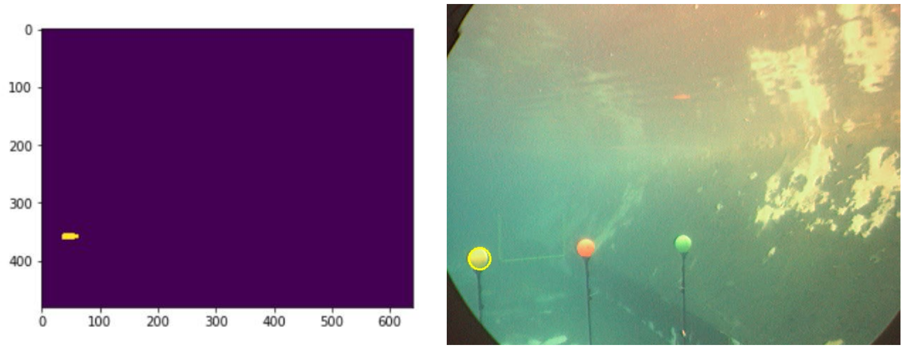

Figure 10: Yellow Buoy Segmentation

5 Discussions

1. Using three 1-D Gaussian on only the green channel of the green buoy gave good results with some background error. Background error can be removed by using morphological operations such as dilation and erosion as well as using the other 2 channels. Background error can also be removed by using contouring operations. But the downside of only using contouring operation is that it does not work on all the frames. Using contouring operations after morphological operations gave us good results.

2. Yellow buoy was the most difficult to identify as the yellow color background error due to sunlight is present in the initial frames of the video.

3. Using different color space such as HSV and RGBY can be used for this project. RGBY has its own yellow channel, hence will make it easier to detect yellow color buoy in the input video.

4. We also tried to convert the image from RGB to LAB and performed CLAHE(Contrast Limited Adaptive Histogram Equalization) which provided similar results to that of Average Histogram.

6 Results

The output video pertaining to the project can be found in the below link

- Green Buoy Detection
- Yellow Buoy Detection