



UNIVERSITY OF BORDEAUX

INTERNSHIP REPORT

MASTER OF SOFTWARE ENGINEERING (2013 - 2015)

**Design and programming of automatic
classification methods applied to biological
images**

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Abstract

Image processing is a field that has many application in life. It can be from the usual application to the application in medicine or cosmology. To obtain the best result, all most of applications must follow two processes: Firstly, we should pre-process the image with some appropriate operations to enhance the interest in also reduce the noises. Secondly, we apply main operations to obtain the result.

The goal of project is built a program with full functions about processing base on the biological images. During my internship at LaBRI, my tasks are developing the algorithm to identify automatically landmarks on biological images and classify the biological images. Besides, we also program method to preprocessing image by removing the unexpected parts. The method based on the segmentation and classification.

Finally, I integrated my functions into the IMP tool, which was developed by NGUYEN Hoang Thao. Besides, we also debug the previous code and write the documentation for the next development.

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Chapter 1

Introduction

1.1 Pôle Universitaire Français

The Pôle Universitaire Français (PUF) was created by the intergovernmental agreement of VietNam and France in October 2004. With ambition is building a linking program between the universities in VietNam and the advanced programs of universities in France. There are two PUF's center in VietNam: Pôle Universitaire Français de l'Université National du Vietnam - Ha Noi located in Ha Noi capital (PUF-Ha Noi) and Pôle Universitaire Français de l'Université National du Vietnam - Ho Chi Minh Ville located in Ho Chi Minh city (PUF-HCM).

1.1.1 PUF-Ha Noi

PUF-Ha Noi is regarded as a nursery for the linking program, it support on administrative procedure and logistics for the early year of program. Besides, PUF-Ha Noi also implement the training program regularly about Master 2 provided by universities and academies in France. About administration, PUF-HN directly under Institut Francophone International (IFI), which was created by VietNam National University at HaNoi in 2012.

1.1.2 PUF-HCM

PUF-HCM¹ is a department of VietNam National University at Ho Chi Minh city. From the first year of operations, PUF-HCM launched the quality training programs from France in VietNam. With target, bring the programs which designed and evaluated by the international standards for Vietnamese student. PUF-HCM always strive in our training work.

¹<http://pufhcm.edu.vn>

So far, PUF-HCM have five linking programs with the universities in France, and the programs are organized into the subjects: Commerce, Economic, Management and Informatics. In detail:

- Bachelor and Master of Economics : linking program with University of Toulouse 1 Capitole
- Bachelor and Master of Informatics: linking program with University of Bordeaux and University of Paris 6.

The courses in PUF-HCM are provided in French, English and Vietnamese by both Vietnamese and French professors. The highlight of the programs are inspection and diploma was done by the French universities.

1.2 Laboratoire Bordelais de Recherche en Informatique

The Laboratoire Bordelais de Recherche en Informatique (LaBRI)² is a research unit associated with the CNRS (URM 5800), the University of Bordeaux and the Bordeaux INP. Since 2002, it has been the partner of Inria. It has significantly increased in staff numbers over recent years. In March 2015, it had a total of 320 members including 113 teaching/research staff (University of Bordeaux and Bordeaux INP), 37 research staff (CNRS and Inria), 22 administrative and technical (University of Bordeaux, Bordeaux INP, CNRS and Inria) and more than 140 doctoral students and post-docs. The LaBRI's missions are: research (pure and applied), technology application and transfer and training.

Today the members of the laboratory are grouped in six teams, each one combining basic research, applied research and technology transfer:

- Combinatorics and Algorithmic
- Image and Sound
- Formal Methods
- Models and Algorithms for Bio-informatics and Data Visualisation
- Programming, Networks and Systems
- Supports and Algorithms for High Performance Numerical Applications

²<http://www.labri.fr>

Within these team, research activities are conducted in partnership with Inria. Besides that, LaBRI also collaborate with many other laboratories and companies on French, European and the international.

1.3 The Internship

The internship is considered a duration to apply the knowledge to the real environment. It shows the ability synthesis, evaluation and self-research of student. Besides, the student can study the experience from the real working. My internship is done under the guidance of Prof. Marie BEURTON-AIMAR in a period of six months at LaBRI laboratory.

1.3.1 Objectives and my task

In any fields, constructing and developing a tool to support fully operations need a period of time. With the expect, creating a tool to support the operations about image processing, IMP was created. Begin in 2012, IMP was created by NGUYEN Hoang Thao. In the first version, IMP had basic operations about image processing such as segmentation, smoothly, morphology, transform,... . Besides, it also integrated some algorithm which was processing on image.

As a part of IMP, the general objectives of this internship is developing the operations in the IMP tool, as follows:

- Design and implementation the method to remove the grid on biological images
- Design and program the method to automatic classification on biological images
- Automatic detect the landmarks on biological images
- Maintain some operations in IMP

1.3.2 Organization of the document

The all report mainly have seven chapters. In the chapter 1, this is the short introduction about my university, mainly information about the laboratory where I do the internship and the objectives of my internship. Chapter 2, introduce about the necessary preliminaries in image processing field which we use to implement the methods. In the chapter 3, I propose the algorithm to preprocessing image, with the aim is decrease the noise in the input and increase the effective of the classification methods. In the chapter 4, I mention method to

segmentation image, classification objects and an automatic process detect the landmarks on the biological images. Chapter 5, I present about the main implementation of the preprocessing image algorithm and classification methods. Chapter 6, we show the parameters which using in the program to test. Besides, this chapter also show the results when testing on two set of images. Finally, chapter 7, we have a short summary about the work and describe about the work in the future.

Chapter 2

Background

2.1 Overview about image processing

Nowadays, we have a lot of programs what used to edit the photos (e.g. photoshop, gimp, paint,...). By apply some technique, we can effectively some property to change the image such as: scaling, blurring, rotating image,.... Actually, an image is presented of a set of pixels. Each pixel carry a value which presented for the color at this location. When combine the value of all pixels, we have the image as we can see in the real word. The changing on image really changing the value on each pixel in image. Behind the techniques in these programs are mathematical operations and the field using mathematical operation on an input image, called *image processing*. The output of image processing may be either an image or a set of characteristics related to the image. And most of image processing technique are performed on two-dimensional image. In image processing, we have a lot of operations. In this chapter, we just introduce some basis operations what often useful for the object of this internship.

2.2 Image filtering

Image filtering is a process to modify or enhance the quality of images. This is known as a “neighborhood” operation. The neighborhood is a set of pixels around a selected pixel. In image processing, with a pixel, we can have 4-neighbors or 8-neighbors of it. Image filtering determines the value at the selected pixel by apply some operations with the value of its neighbors. One of the filter operators is smoothing, also called blurring. This technique is used in preprocessing steps, particularly using for noise reduction. With a matrix called kernel. It was sliding over the image. At each position, the output of value at this position is average of its neighborhoods.

In image processing, we have many filter techniques. But it can be divided into 2 main types:

Linear filter: The idea behind this filter is replacing the value of every pixel in the image by the average of the gray levels in the neighborhood defined by the filter mask. By this work, this filter sometime are called averaging filter. The result of this process is an image with reduced the sharp edges in gray level, it also reduce the noise because the noise is typically and random in the image. The mask is a matrix useful for blurring, sharpening, or edge-detection, The output image is accomplished by convoluting between a mask and an image.

Order-Statistics filter: By ordering the pixels in the image and then replacing the value of the center pixel with the value determined by the ranking result. Median filter is an example of this technique.

2.3 Histogram

Histogram is a representation about distribution of data on the regions (we called bin) in the data range. The bins are the number of sub-ranges when we divide the entire data range into several small interval (i.e. With the range from 0 - 255 and the size of each sub-range (bin) is 16, the number of bins is $256/16 = 16$ bins. The first bin range is 0 - 15, the second range is 15 - 30, and so on). The value at each bin is the number of data which have value belong to this bin. Normally, histogram represented by the columns chart with x-axis represented for the number of bins, and y-axis represented for the value of each bin.

Histogram can be used effectively for image enhancement, also useful in many image processing applications, such as image compression and segmentation.

Histogram equation: is a method allow adjust the contrast using the histogram of image. It

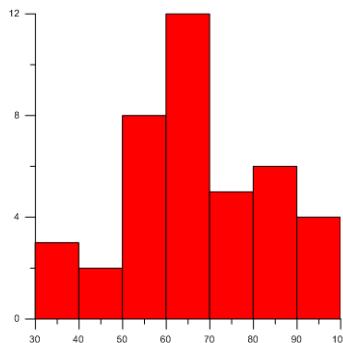


Figure 2.1: An example about histogram

mapping one distribution on a histogram to a wider distribution of intensity values. By this, the image can brighter.

Histogram matching: is a method adjustment of two image using the histogram. This method was finished by calculating the cumulative distribution functions of two histograms and find the histogram matching function. Finally, apply the matching function on each pixel of the image to get the result.

2.4 Segmentation

Segmentation subdivides an image into its regions. The size of regions is depend on the problem being solved. This mean, segmentation should stop when the regions of interest in application have been detected. In the real, the segmentation was applied into many fields such as machine vision, medical imaging, object detection, etc. The most of segmentation algorithms are based on the basic properties of intensity values: discontinuity and similarity. In the first case, the segmentation based on abrupt changes in intensity. The second case, the image segmentation based on a predefined criteria. It means the image was segmented into regions that are similar according to a set of criteria. And, we have many the method to segment an image such as thresholding method, region growing, clustering method, histogram-based method, etc.

Thresholding is a simplest method of image segmentation. Thresholding use a particular threshold value “ t ”, we split the image into two parts: the first part includes pixels which have the value greater than t , and the second part contains the pixels vice versa. With this technique, thresholding can be used to create an binary image from a gray scale image. In fact, we have many type of threshold, as follows:

- *Global thresholding*, when t is a constant over an entire image
- *Variable thresholding*, when t changes over an image
- *Local or regional thresholding*, is variable threshoding in a region of an image
- *Dynamic or adaptive thresholding*, if t depends on the spatial coordinates.
- *Multiple thresholding*, thresholding on 3 dominant modes (color image)

Canny algorithm is an edge detection algorithm that uses to detect the structure of image. The process of this algorithm can break into the steps follows ¹:

¹https://en.wikipedia.org/wiki/Canny_edge_detector

- Apply the Gaussian filter to smooth the image (remove the noise)
- Find the intensity gradients of the image
- Apply non-maximum suppression to get rid of spurious response to edge detection
- Apply double threshold to determine potential edges
- Track edges

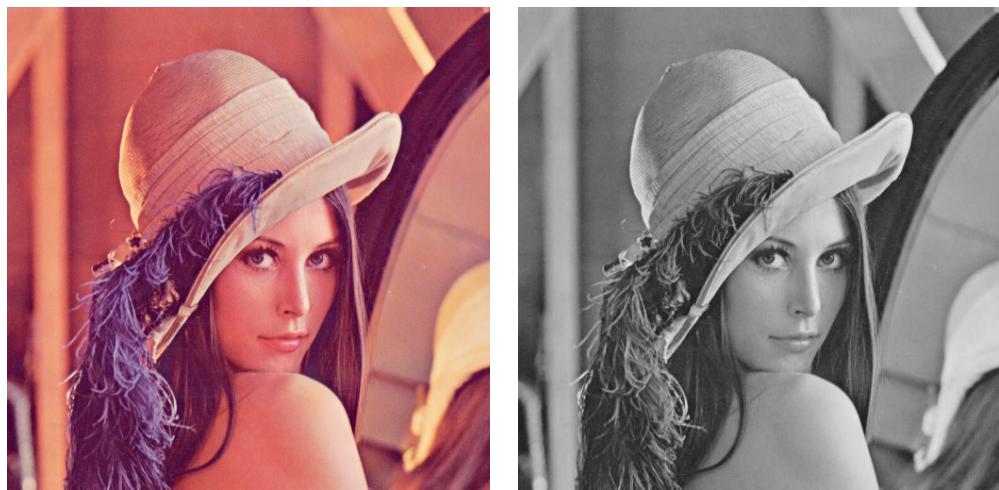
2.5 Color processing^[3]

The use of color in image processing do not just identify or extract an objects from scene, it also a factor for image analysis. Color processing can be effect on each component image individually or work directly with pixels based on a color model. The color models is a specification of colors in some standard, generally accept way such as BGR, CMY, HSV or Grayscale model.

- BGR model: using blue, green, red as three primary colors. Image presented in this model consist of three components images for each primary color.
- CMY model: used for hardcopy devices. Based on the BGR mode, each value in CMY mode was computed by integrate between 2 primary color in BGR. Specific, C (cyan) is consist from green and blue, M (magenta) is consist from red and blue and Y (yellow) is consist from red and green.
- HSV model: difference with BGR, HSV using the 3 components are hue, saturation and brightness to present image. Hue is a color attribute which describe a pure color (yellow, orange, red) and saturation give a degree to pick the pure color is diluted by white light. Brightness is a notation of intensity for color sensation.
- Grayscale model: The colors in grayscale just black and white because it just carry the intensity information on each pixel. Because that, the image in grayscale mode was called black and white image. The color of each pixels in image from black, where have weakest intensity to white at the strongest intensity.

The most color operations in image processing is transformation. This is a process to the conversion image between the color models by using a transform expression such as BGR to HSV, HSV to BGR, BGR to Grayscale.

Besides that, considering the specific characteristic of each color space, allowing we can classify the pixels in the image. This idea can be used to segment object of an image. HSV model is widely used to compare the color because the range of color (Hue value) is specific.



(a) An image in BGR mode

(b) An image in Gray mode

Figure 2.2: The images with color transformation from BGR to Gray

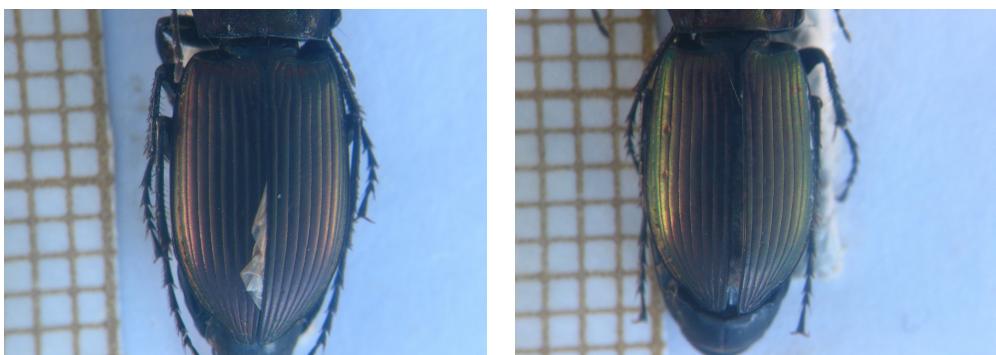
Chapter 3

Preprocessing image

Preprocessing image is a process that reducing the noises or removing the unexpected objects on image. It is used to enhance the quality of input dataset (images) when do a test for a algorithm or a method. Following the requests, we can apply one or more operations to pre-process image. In this chapter, we will discuss about a method to pre-process image within this internship. The method suggested base on the basic knowledge about the operations in image processing.

3.1 Problem

With the input dataset is a set of 293 insect images. Each image contains the parts of insect(body, head,...) and an unexpected object, specifically yellow grid (figure 6.1). To enhance the accuracy of classify method, we need to remove the grid and just keep the insect on each input image.



(a) The yellow grid on the left of insect

(b) The insect overlap the yellow grid

Figure 3.1: The input images with yellow grid

3.2 Analysis

Each input image contains the two objects: a part of insect (called insect) and the yellow grid (called grid). About the relative position, the grid always stayed in the left of insect, and insect can either overlap the grid. About the color, images are presented in BGR model with three main color groups: the background color, the yellow color of grid and the color of insect.

The method proposed to remove the grid based on the color processing. If we process the image in BGR model, the algorithm may be complex because the color at each pixel is combined of three values (blue, green, red). While HSV model has a specific channel to present the colors with clear range. We can apply this property for detecting and removing the grid. The proposed process to remove the grid as follows:

1. Find the “*limit*” point of grid: the points stay nearest outside grid.
2. Find the “*replace*” point: location that its value used to replace for grid.
3. Replace the grid by the value at “*replace*” point.

3.2.1 Finding the limiting and the replacing point

Browsing image to check and replace the pixels in grid need a long time. To reduce the time to do that, we should find the limit range of grid. The limit of grid is the points located out of grid and its closest. Instance of checking on all pixel, we just check the pixels stay on the left of limit points. So, The idea to find the limiting point outside of grid is finding a column that the number of *yellow* points stay on this column keep within permitted level.

Because the grid always stayed in the left of image and the width usually less than a two-thirds of width of image. So, to reduce the finding time, we also check from the begin of image to two-thirds of image. The result of this step is the limit points, these used for limiting the length when we check the pixels on yellow grid.

The algorithm to find the limit points are followed:

Data: *inputImage*: The input image (contains the insect and grid)

Result: The coordinate of limit point

```
1 Declare some variables: Mat hsvImage; vector <Mat> hsv_channel;  
2 Convert image from BGR to HSV:  
    cv : cvtColor(inputImage, hsvImage, COLOR_BGR2HSV) ;  
3 Split HSV image into several channel: cv :: split(hsvImage, hsv_channels);  
4 Set up initial limit_point and assign with the left-top corner: Point  
    limit_point = Point(0, 0);  
5 Declare a variable yellow_count to count the number yellow points on each columns  
when processing,:  
6 for j ← 10 to image_width * 2/3 do  
7     if H value at (5, j) > 100 || (H value at (5, j) > 70 && H value at (5, j) < 100  
        && S value at (5, j) < 10 && V value at (5, j) > 175 ) then  
        limit_point.x ← j;  
        limit_point.y ← 0;  
        yellow_count ← 0;  
12     for i ← 1 to hsv_channel[0].rows * 2/3 do  
13         if H value at (i, j) <= 38 then  
14             yellow_count + +;  
15             if yellow_count >= 8 then  
16                 limit_point.x ← 0;  
17                 limit_point.y ← 0;  
18                 break;  
19             end  
20         end  
21     end  
22     if limit_point.x! = 0 then  
23         break;  
24     end  
25 end  
26 end  
27 if limit_point.x == 0 then  
28     limit_point.x ← hsv_channel[0].columns/3 + 200;  
29     limit_point.y ← 0;  
30 end
```

Now, we indicate which is the color used to replace the yellow points. Hence, we choose the points having the value nearest with the background color. The histogram is ideal for choosing the position to replace, but we also have some conditions to obtain a good value.

The algorithm to find the replacing points are followed:

Data: inputImage: the input image

Result: The coordinate of replacing point

```

1 Convert image to gray scale image;
2 Calculate the histogram on gray scale image and mean of histogram;
3 Split the HSV image into channels;
4 for  $i \leftarrow 0$  to  $grayImage.rows$  do
5   for  $j \leftarrow 0$  to  $grayImage.columns$  do
6     if value at  $(i, j) > mean$  of histogram
7       &&  $H$  value  $(i, j) > 90$ 
8       &&  $H$  value  $(i, j) > 130$ 
9       &&  $S$  value at  $(i, j) > 50$ 
10      &&  $V$  value at  $(i, j) > 215$  then
11        return this position ;
12      end
13    end
14 end

```

Algorithm 2: Algorithm to find the replacing point

3.2.2 Replacing the grid

The grid does not just contain the yellow points. It also contains the points which have the similar color with background but the brightness is difference (called *miss bright* points). So, replacing the grid means replace both of yellow and *miss bright* points.

After having the limit and replace point, we can replace the grid by processing on all rows of image. On each row, we replace the value at each pixel by the value at replace point. This work repeated until meeting the limit points or a “special point” (called “break” point). It can be a point stayed on the insect or a point belong to background.

For each part of the insect, the color of insect or the background also have the difference values. So, we need to define the difference special value (break point) for each part based on the file name of image.

Data: filePath: the file path of image

Result: Which part of insect in image

```
1 QString temp ← filePath.toLower();  
2 if temp contains "ely" then  
3   | return ELYTRE;  
4 end  
5 if temp contains "md" then  
6   | return MDROITE;  
7 end  
8 if temp contains "mg" then  
9   | return MGAUCHE;  
10 end  
11 if temp contains "prono" then  
12   | return PRONOTUM;  
13 end  
14 if temp contains "tete" then  
15   | return TETE;  
16 end  
17 return ELYTRE;
```

Algorithm 3: Algorithm to get the parts of insect

Data: inputImage: the input image; limit_point: the limit point; part: part of insect;
minBrightness: minimum of brightness; rpoint: replacing point

Result: The image after replace the yellow grid

```

1 for  $i \leftarrow 0$  to  $inputImage.rows$  do
2   for  $j \leftarrow 0$  to  $limit\_point.x$  do
3     if part is ELYTRE then
4       if value at  $(i, j + 50)$  satisfy breaking condition then
5         break;
6       end
7     end
8     if part is MDROITE or MGAUCHE then
9       if value at  $(i, j + 50)$  satisfy breaking condition then
10        break;
11       end
12     end
13     if part is PRONOTUM then
14       if value at  $(i, j + 50)$  satisfy breaking condition then
15         break;
16       end
17     end
18     if part is TETE then
19       if value at  $(i, j + 50)$  satisfy breaking condition then
20         break;
21       end
22     end
23     if H value at  $(i, j + 50)$  in yellow range then
24       replace value at this point by the value at replacing point;
25     end
26     else if V at  $(i, j + 50) > minBrightness$  then
27       replace value at this point by the value at replacing point;
28     end
29   ;
30 end
31 end

```

Chapter 4

Classification methods

In previous chapter, we introduce a method to remove the unexpected object. In this chapter, we will implement a method to obtain the features what we are interested in and the method to detect the landmarks on the insect. This method was proposed by Palaniswamy^[4]. The processes can be discuss in follow steps:

1. Extracting the features:
2. Constructing and comparing the pairwise geometric histogram
3. Estimating the pose by the probabilistic Hough transform
4. Detecting the landmarks by template matching
5. Classifying by statistical method

4.1 Preprocessing image and feature extraction

To obtain the good result, before extracting the features in the image, we need to pre-process the image with a appropriate technique to reduce the noise as well as enhance the features that we care. Feature extraction is a process extracting interested features from digital image. The expect result in this result is list of approximate lines which use to construct the pairwise geometric histogram.

The process mainly separate into two stages: Firstly, we pre-process image. In this stage, we reduce the noise in image by finding a threshold value and apply the thresholding technique to obtain the interested features. Secondly, we extract the features based on the edge segmentation.

By applying the appropriate technique to obtain the step edges and broken the edges into approximate lines.

4.1.1 Preprocess image

In this application, we use the thresholding technique to pre-process the image. In thresholding technique, with a threshold value “ t ”, we can decrease the noise and obtain the interested features. The threshold value can be defined by the histogram analysis.

Based on the histogram of the original image, we compute the mean and median of this histogram. With the histogram obtained, we split it into two parts: the first part begin from the bin 0 to the limit value (the limit value is smallest value between mean and median); the second part, starting from the limit value to the end of histogram. For each part, we find the maximum, minimum value and calculating the mean of it. The value “ t ” obtained by the mean of two mean values in two parts of histogram.

With the threshold value “ t ”, we apply the threshold technique to pre-process image in the CV_THRESH_BINARY mode (keep the pixel has value greater than threshold value).

Data: inputImage: the input image

Result: outputImage: the image after processing

- 1 Convert the input image into gray scale image;
- 2 Calculate the histogram on gray scale image and store the result in *histogram* variable ;
- 3 Compute the *mean* value and *median* value of histogram;
- 4 $limit \leftarrow (mean > median ? median : mean);$
- 5 $limitSub \leftarrow ((limit >= 120) ? (limit - 25) : (limit - 5));$
- 6 Declare some variables: *int imax* $\leftarrow -1$, *max* $\leftarrow -1$;
- 7 **for** $i \leftarrow 0$ to *limitSub* **do**
 - 8 **if** *histogram*[*i*] $> max$ **then**
 - 9 *max* = *histogram*[*i*];
 - 10 *imax* = *i*;
 - 11 **end**
- 12 **end**
- 13 Declare some variables: *int imin* $\leftarrow -1$, *min* $\leftarrow max$;
- 14 **for** *k* $\leftarrow imax$ to *limit* **do**
 - 15 **if** *histogram*[*k*] $< min$ **then**
 - 16 *min* = *histogram*[*k*];
 - 17 *imin* = *k*;
 - 18 **end**
- 19 **end**
- 20 Declare some variables: *int max2* $\leftarrow -1$, *imax2* $\leftarrow -1$;
- 21 **for** *j* $\leftarrow limit$ to *end_of_histogram* **do**
 - 22 **if** *histogram*[*j*] $> max2$ **then**
 - 23 *max2* = *histogram*[*j*];
 - 24 *imax2* = *j*;
 - 25 **end**
- 26 **end**
- 27 $middle1 \leftarrow (imax1 + imin)/2$;
- 28 $middle2 \leftarrow (imax2 + imin)/2$;
- 29 $middle \leftarrow (middle1 + middle2)/2$;
- 30 Apply the threshold with threshold value is *middle*;

Algorithm 5: Algorithm to preprocess image

4.1.2 Feature extraction

After apply the threshold to pre-process image, we apply the Canny algorithm to detect the step edges, which incorporates non-maximal suppression and hysteresis thresholding. In Canny, the importance parameters are two threshold values and aperture size for the Sobel operator, it decides the pixels kept. The threshold value used in Canny algorithm also the value used in the previous step, and the ratio between lower threshold and upper threshold is 1 : 3 (follows the article [4] but have to modified). In implementation, the Canny operation used from OpenCV library¹, and the parameters need to put into Canny are:

- source: the input image (in grayscale mode)
- destination: the output image
- low_thresh: the first (lower) threshold value
- high_thresh: the second (upper) threshold value
- kernel_size: size of kernel, aperture for the Sobel operator

The Canny algorithm is not aware of actual edges, the edge detecting was based on the Sobel operator, extracted with non-maximal suppression. So, to obtain the expect result, we need to apply another technique to obtain the step edges. The **findContours** was chosen for this aim, the result is a vector of the edges, and each edge was presented by a vector of the points. Like the Canny, the **findContours** also used from OpenCV library² and the parameters used in this operation as follows:

- source: the binary input image
- contours: the output. Each contours is stored in a vector of points.
- hierarchy: optional output vector, containing information about the image topology.
- mode: contours retrieve mode
- method: contours approximation method
- offset: optional offset by which every contour point is shifted.

¹http://docs.opencv.org/modules/imgproc/doc/feature_detection.html#canny

²http://docs.opencv.org/modules/imgproc/doc/structural_analysis_and_shape_descriptors.html#findcontours

4.1.3 Edge segmentation

The geometric relation can not be constructed from the edges, it always constructs from the relation of basic geometric objects, such as the lines. In fact, any arbitrary edge can be represented by a set of approximate lines. Instead of representing an edge, we can represent a set of approximate lines of it. This way is also useful when we want to present the edges or describe the relation between them. With the set of step edges was obtained from find contours (the image structure). In this step, we will segment it to approximated lines. The method to segment the edges is a recursive algorithm^[5] but it has some changes in the “stop condition” of the algorithm to easily process, as follows:

- Establish a line “ l ” between two endpoints of edge.
- For each point on edge, we compute the perpendicular distance from it to the line l and keep the point which has the maximum perpendicular distance.
- If the maximum perpendicular distance from a point on edge to the line l is greater than α , then the edge is split at this point. The value chosen for α in the program is 3 ($\alpha = 3$).
- Reprocess both parts which were obtained from step 3.
- The algorithm continues until all edges fragments are represented.

The algorithm is presented as follows:

Data: listPoints: list of points which presented the edge

Result: Queue of “step” points on the edge

```
1 Declare the first endpoint:  $p0 \leftarrow listPoints[0]$ ;  
2 Declare the second endpoint:  $pend \leftarrow listPoints[size - 1]$ , size is the size of  
listPoints;  
3 Set up a straight line between the two endpoints  $p0, pend$  (line  $d$ );  
4 Initialization the max value:  $maxDistance \leftarrow 0$ ;  
5 Declare a “split point”:  $imax \leftarrow 0$  ;  
6 Declare a variable:  $distance \leftarrow 0$ ;  
7 for point  $p$  in listPoints do  
8      $distance \leftarrow$  from  $p$  to line  $d$ ;  
9     if  $distance > max\_distance$  then  
10         $maxDistance \leftarrow distance$ ;  
11         $imax \leftarrow$  position of  $p$ ;  
12    end  
13 end  
14 if  $maxDistance > 3$  then  
15    split the list of points at  $imax$  and put into 2 parts ( $part1, part2$ );  
16    Pre-process on  $part1$ ;  
17    Pre-process on  $part2$ ;  
18 end  
19 if  $p0$  does not exist in result queue then  
20    push  $p0$  into queue;  
21    // queue is a variable of class  
22 end  
23 if  $pend$  does not exist in result queue then  
24    push  $pend$  into queue;  
25    // queue is a variable of class  
26 end
```

Algorithm 6: Algorithm to segment an edge

4.2 Pairwise geometric histogram

Pairwise geometric histogram(PGH)^[2] is used to encode the relative information between a line and a set of lines in an object. Therefore, an object can be represented by a set of PGH. From the set of PGH, we can reconstruct the object or compare with another object. In this section, we will mention the constructing a PGH for an object based on the geometrical relationship and compute the similar distance between two objects.

4.2.1 Local pairwise geometric histogram

The PGH is constructed on the geometric features between lines relative. The geometric features are characteristic which can describe the geometric shape such as angle, the length of line, perpendicular between two lines, For the shape representation, the relative angle and perpendicular distance is geometrical features useful.

The Local PGH presented the relationship between a reference line with other lines. The procedure to construct the PGH between two lines was described in below:

- Choose the reference line (other lines called object lines)
- Compute the angle between reference line and the object lines
- Calculate the perpendicular distance from two endpoints of object lines to the reference line (assigned d_{min} and d_{max}).
- Recording the perpendicular distance and angle relative between reference line and the object lines into the two dimensional histogram.

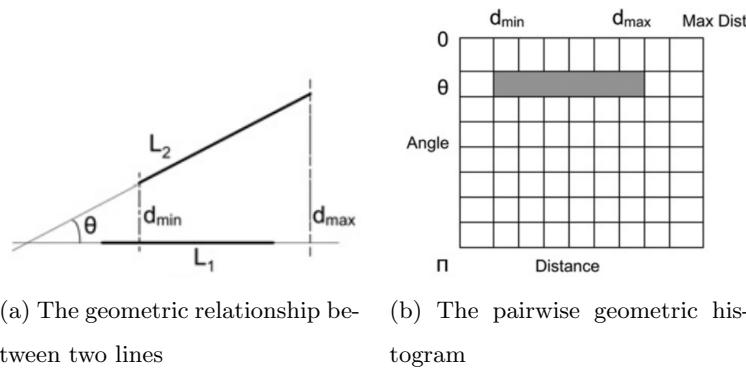


Figure 4.1: Example about geometric features and the pairwise geometric histogram

The frequency of the geometric features is recorded as a two dimensional histogram with an angle axis ($0 - \pi$) and distance axis (range of perpendicular distance, d_{max} is the maximum distance on all distance of two arbitrary lines). The entries on PGH describe the geometric relationship between the reference line and the object lines. The blurring of entry along the axis regarding the true position and orientation of each object lines for reference line. Following the accuracy, we can indicate the size of histogram and normalize the value to match with size of histogram.

4.2.2 Global pairwise histogram

Based on the constructor of a line in object. The object encoded by recording PGH for all lines within object. If the object is defined by n lines, the full shape representation will composed of n pairwise geometric histograms. This method still good when we apply some variants on the image, such as translate or rotate the image because the angle and perpendicular distance between a pair of lines is invariant.

4.2.3 Histogram matching

“The histogram matching enables robust classification of shape features by finding similarity between the scene and reference model”^[4]. The similar between two models can obtain via the similar distance, which was computed by comparing their probability distribution on geometric histogram. In program, each image was represented by a comprises of many geometric histograms and using the Bhattacharya metric to determine the similar distance between two models ^[4]. In general, we have normalize the histograms before comparing. The form of Bhattacharya metric used to compute the degree of 2 model:

$$d_{Bhattacharyya}(H_i H_j) = \sum_{\theta}^{\pi} \sum_d^{d_{max}} \sqrt{H_i(\theta, d) H_j(\theta, d)} \quad (4.1)$$

The significance of parameters in the formula 4.1, as follows:

- θ : angle value, range of θ in angle axis from 0 to π .
- d : the perpendicular distance, range of d in perpendicular distance from 0 to the maximum distance of arbitrary lines of shape.

- $H_i(\theta, d)$ is an entry at row θ and column d in histogram of image i
- $H_j(\theta, d)$ is an entry at row θ and column d in histogram of image j

By the default, the range of angle axis from 0 to 180 degree (correspondence with 180 degree). Based on the accuracy of program, we can increase the range of angle axis. This design allow increase the range of angle axis to several time with default value. Example, the table below show the result when calculating Bhattacharya distance between image *Md 028.JPG* and some images with difference accuracy:

Reference image	Scene image	180	2 * 180	4 * 180	6 * 180
Md 028.JPG	Md 001.JPG	0.977953	0.964167	0.93861	0.91471
Md 028.JPG	Md 005.JPG	0.96479	0.943657	0.906444	0.871756
Md 028.JPG	Md 010.JPG	0.976241	0.958061	0.925943	0.896445
Md 028.JPG	Md 027.JPG	0.980728	0.968233	0.945442	0.92485

Besides the Bhattacharya metric, we can also choose another metric to matching the histograms, such as: **Chi-squared** metric and **Intersection** metric. The forms was presented as below:

Chi-squared metric:

$$d_{Chi-squared}(H_i H_j) = \frac{\sum_{\theta}^{\pi} \sum_{d}^{d_{max}} \left(\frac{(H_i(\theta, d) - H_j(\theta, d))^2}{(H_i(\theta, d) + H_j(\theta, d))} \right)}{2} \quad (4.2)$$

Intersection metric

$$d_{Intersection}(H_i H_j) = \sum_{\theta}^{\pi} \sum_{d}^{d_{max}} \min(H_i(\theta, d), H_j(\theta, d)) \quad (4.3)$$

The significance of parameters in equation (4.2) and (4.3) is similar with (4.1). For the Bhattacharyya and Intersection metric, the perfect match is 1 and the total mismatch is 0. The result is opposite to Chi-squared metric (0 for perfect match and 1 for total mismatch).

Hence, depend on the purpose of comparison will choose a suitable comparing method. In this program, we want to try on three method to have a general view result when matching the histograms.

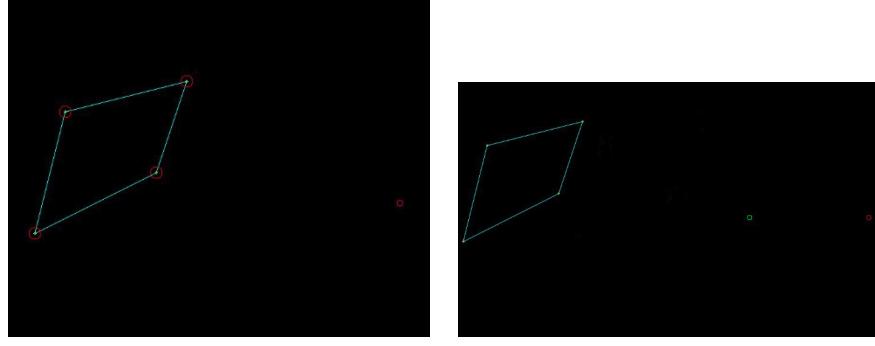
4.2.4 Probabilistic Hough transform

The probabilistic Hough transform (PHT) used to estimate the global shape^[1]. Based on a group of features within the scene, identifying the present of a model image in a scene image. The hypothesised location of the model in the scene is indicated based on the conditional probability that any pair scene lines agreement about a position in model.

Estimating the global shape has two main stages. Firstly, training process begin by recording the perpendicular distance and the angle from a reference point to each pair of model lines. Secondly, predicting the pose of scene difference from the model, then we estimate the location of the landmarks. We create a Hough space to store value when exist a pair of scene lines match with the entry in training process. The peak in Hough space is assumed of the reference point of the model in the scene. From this reference point, we can estimate the reference landmarks of reference image on the scene. The process to estimate the global pose is described as follows:

- Choose a arbitrary point in model as reference point
- For each pair lines in model, calculating and recording the perpendicular distance and angle from the reference point to each line.
- Create an two dimensional accumulator, one dimension for the angle and another for the perpendicular distance.
- For each pair lines in scene, finding the entry correspond about position, orientation and scale. Increase the value at correlative cell in the accumulator (indicate by the angle and distance).
- Compute the maximum value in accumulator.
- Indicating the pair of scene lines and the entry with maximal value of accumulator.
- Extending the perpendicular lines of the pair of scene lines at the appropriate position. The intersection of them is the location of reference point in the scene.

In the example below, we apply the PHT to estimate the landmarks of model in the scene. The image in figure 6.1a as the model. In the model, the small red circle and large red circles are the reference point and the landmarks in model, respectively. The image in figure 6.1b as scene. By applying the PHT, we can estimate the reference point (green circle) in the scene and the location of the landmarks (the yellow circles).



(a) The model image

(b) The scene image

Figure 4.2: The landmarks estimated by probabilistic Hough transform

Training process

In this step, recording the perpendicular distance and angle from each pair model lines to a reference point (called reference table). The reference point can be chosen at arbitrary position on model image. To save the time to process at the next step, we just consider the “closet pair lines”. In this application, the reference point chosen at the center of image and the closet pair lines are pair of lines have all three conditions: the length of each line greater than 60 pixels, the lines are not parallel and the distance between it less than 5 pixels. The algorithm to consider a pair closet lines and construct the reference table as follows:

Data: line1 (the first line), line2 (the second line)

Result: Two line closet or not (bool)

```

1 distance1 ← distance from the first endpoint of line1 to line2;
2 distance2 ← distance from the second endpoint of line1 to line2;
3 if line1.length() > 60 and line2.length() > 60
4 and line1 not parallel with line2
5 and (distance1 <= 5 or ditance2 <= 5 ) then
6   |
7   |   return true;
8 end
9 return false;
```

Algorithm 7: Algorithm to consider the closet lines

Data: lines (a list of lines), refPoint (the reference point)

Result: The reference table

```
1 Declare the reference table refTable ;  
2 for line i in lines.size() do  
3   for line j in lines.size() do  
4     if i != j and line(i) closet with line(j) then  
5       Compute the angle and perpendicular distance from line(i) to refPoint;  
6       Compute the angle and perpendicular distance from line(j) to refPoint;  
7       Create an entry to store pair of lines and its information ;  
8       Add the entry into reference table ;  
9     end  
10   end  
11 end  
12 return reference table ;
```

Algorithm 8: Algorithm to construct the reference table

Estimating process

The estimating process is duration estimate the reference landmarks on the scene image. Firstly, we need to find the reference point on scene image. Secondly, we estimate the reference landmarks on the scene image from the reference point.

By finding a pair of scene lines agree with a pair of model lines, we can detect the position of the reference point on scene image. We create an accumulator to store each agreement between pair of scene lines and pair of model lines. For each pair of scene lines, we find its exist in the reference table and increase the value at correspondence position in accumulator. At the end, we can obtain the pair of scene lines and pair of model lines correspondence with the maximum value in accumulator. By extending the perpendicular lines of the pair of scene lines at the appropriate position, we can meet the reference point at the intersection of them.

In this program, two pair lines called agreement if the angle difference between them less than one degree and the length scale less than two. Two algorithm followed describe the definition between two pair lines and finding the position of reference point in scene image.

Data: *line1* (the first reference line), *line2* (the second reference line), *sline1* (the first scene line), *sline2* (the second scene line)

Result: Two pair lines similar or not (boo)

```
1 angle1 ← angle between line1 and line2;  
2 angle2 ← angle between sline1 and sline2;  
3 if  $abs(angle1 - angle2) < 1$  and  $abs(line1.length() / sline1.length() -$   
 $line2.length() / sline2.length()) < 2$  then  
4   return true;  
5 end  
6 return false ;
```

Algorithm 9: Algorithm to check the agreement between two pair lines

Data: *refTable* (the reference table), *slines* (pair of scene lines)

Result: The entry in reference table

```
1 Declare the entry in reference table entry ;  
2 for entry et in refTable do  
3   if agree between lines in entry and slines then  
4     entry ← et;  
5   end  
6 end  
7 return entry ;
```

Algorithm 10: Algorithm to find the agreement of pair scene lines in model

Data: lines (a list of scene lines), refTable (reference table)

Result: The reference table

```
1 Create an accumulator, acc;  
2 Declare the reference table refTable ;  
3 for line i in lines.size() do  
4     for line j in lines.size() do  
5         if i != j and line(i) closet with line(j) then  
6             Find the agreement of pair scene lines in mode;  
7             Increase the value in acc with correspondence position;  
8             Marked the maximum value, pair of scene lines and entry in reference table;  
9         end  
10    end  
11 end  
12 Find the intersection (intersect) between two perpendicular lines with pair scene lines at  
appropriate position;  
13 // The appropriate position is correct with the distances in reference  
table.  
14 return intersect ;
```

Algorithm 11: Algorithm to find the reference point in scene

By finding the reference point, the landmarks in scene image can be estimated by calculating the relative between the reference point and the reference landmarks. Besides, we also record the difference about rotation, orientation and scale between model image and scene image.

4.2.5 Template matching

Template matching is duration to refine the estimated landmarks on the scene image with an appropriate method.

Cross-correlation

Cross-correlation is a method of estimating the similarity between two signals. By computing the sum of product between 2 signals when sliding, and choose the maximal value. It is used for searching a short signal in a longer signal. In image processing, it used to detect the present of an object (template) in a large object (image). The equation of cross-correlation as follows

(equation 4.6):

$$R_{ccorr}(x, y) = \sum_{x', y'} [T(x'.y').I(x + x', y + y')] \quad (4.4)$$

Where:

- T is template which use to slide and find the exist in other image.
- I is image which we expect to find the template image
- (x', y') are coordinates in template where we get the value to compute.
- $(x + x', y + y')$ are coordinates in image where we get the value to compute when template T sliding.

By sliding the template on image by each pixel from left to right and top to down. At each position, we compute the $R_{ccorr}(x, y)$. The position have maximal $R_{ccorr}(x, y)$ is position that best similar of template in image.

However, if we use the original image to compute and find the similarity, the brightness of template and image can change the conditions and the result. So, we can be normalize the image before apply the cross-correlation to reduce the effect of lighting difference between them.

The normalization coefficient is:

$$Z(x, y) = \sqrt{\sum_{x', y'} T(x'.y')^2 \cdot \sum_{x', y'} I(x + x', y + y')^2} \quad (4.5)$$

The value of this method when we normalized computation as below:

$$R_{ccorr_norm}(x, y) = \frac{R_{ccorr}(x, y)}{Z(x, y)} = \frac{\sum_{x', y'} [T(x'.y').I(x + x', y + y')]}{\sqrt{\sum_{x', y'} T(x'.y')^2 \cdot \sum_{x', y'} I(x + x', y + y')^2}} \quad (4.6)$$

Template matching

Now, back to the our problem. With a reference image and its set of landmarks. We use the cross-correlation to refine the landmarks. In this case, the template is a region around each

landmark in reference image and the image is also a region around the Hough landmark detection in scene image. Hence, to save the time to process, before applying the cross-correlation, the scene image rotated to match with model using Hough estimate.

For each landmarks in reference image, we create a bounding box around the landmarks with an arbitrary size and use landmark as center point. When create the bounding box, we also need to keep the distance between left corner to the landmarks, because sometime, with the landmark position, the size of bounding box can be over the size of image. Use this box as template and do the cross-correlation with each scene image. The results obtained store the location where template match with image. From these position, we can indicate the position of each landmark of reference image on scene image. The algorithm to create the bounding box around a landmark described follows:

Data: image (reference image), landmark (location of a reference landmark), tsize (size of bounding box), distance (to keep the distance from the landmark to bounding box)

Result: A matrix represented for bounding box of landmark

1 Get the matrix of image (image presented by matrix):

```
MatmatImg = image.getMatrix();
2 // Indicate the top left-corner of bounding box:
3 int lx = (landmark.x - tsize/2) < 0 ? 0 : (landmark.x - tsize/2);
4 int yx = (landmark.y - tsize/2) < 0 ? 0 : (landmark.y - tsize/2);
5 // Keep the distance from the landmark to bounding box
6 distance.x = landmark.x - lx;
7 distance.y = landmark.y - ly;
8 // Indicate the low right-corner of bounding box
9 int lx2 = (landmark.x + tsize/2) > matImg.cols ? matImg.cols :
(landmark.x + tsize/2);
10 int yx2 = (landmark.y + tsize/2) < matImg.rows ? matImg.rows :
(landmark.y + tsize/2);
11 // Create the bounding box around landmark
12 Mat box(matImg, Rect(lx, ly, lx2 - lx, ly2 - ly));
13 return the box;
```

Algorithm 12: Algorithm to create a bounding box around a landmark

The below algorithm describe the method to estimate the reference landmarks on scene image

by using cross-correlation. Before applying the cross-correlation, the scene image rotated to match with the model. The angle used to rotate is sum of the difference between the scene line and model line to which it matched and the difference between two pairs of similar lines. To apply the cross correlation, we have used the function *matchTemplate*³ in OpenCV library with matching method is *CV_CCORR_NORMED* (cross-correlation normalize). This function allow we compare the template overlap the image and it support many different methods to match. When the template slide over each pixel on image, the coefficient between them was calculated and stored in a array.

After finished, to get the value and position of maximum value when we compute the coefficient, we use a function in OpenCV, *minMaxLoc*⁴. This method used to detect the minimum and maximum value in an array. Beside that, it also output the location where having the minimum and maximum value.

³http://docs.opencv.org/modules/imgproc/doc/object_detection.html?highlight=matchtemplate#matchtemplate

⁴http://docs.opencv.org/modules/core/doc/operations_on_arrays.html?highlight=minmaxloc#minmaxloc

Data: refImage (reference image), sceneImage (the scene image), lmpath (file path store the reference landmarks)

Result: A list of landmarks on scene image

```

1 Get the reference landmarks from file and store in list refLandmarks;
2 Create a variable to store the new landmarks: sceneLandmarks;
3 Estimate the reference landmarks (refLandmarks) in scene image using probabilistic
Hough transform and save into a variable: esLandmarks;
4 // Get the matrix of scene image
5 sceneMatrix = sceneImage.getMatrix();
6 Rotate the scene matrix with appropriate angle;
7 for variable i in esLandmarks.size() do
8     // Get the reference landmark
9     Point refPoint = refLandmarks.at(i);
10    // Create a bounding box of reference landmark refPoint
11    Mat template = createTemplate(refImage, refPoint, size);
12    // Get the estimate landmark
13    Point esPoint = esLandmarks.at(i);
14    // Create a bounding box of estimate landmark esPoint
15    Mat sceneImg = createTemplate(sceneImage, esPoint, size);
16    Create the matrix to store the value when do the cross-correlation: result ;
17    // Apply the matching and store the result into matrix result
18    cv :: matchTemplate(sceneMatrix, template, result, CV_TM_CCORR_NORMED);
19    // Get the maximum value and position in result matrix
20    double maxValue, minValue;
21    Point maxLoc, minLoc;
22    cv :: minMaxLoc(result, &minValue, &maxValue, &minLoc, &maxLoc, Mat());
23    Compute the position of landmark from maximum position;
24    Push the landmark into the list sceneLandmarks;
25 end
26 Return the list of landmarks;
```

Algorithm 13: Algorithm to get the position of reference landmarks in scene image

Chapter 5

Implementation

5.1 Software architecture

Continue the IMP tool, all the functions for this task was saved in the `impls_2015` package of program. Besides the method was created by myself, I also use some methods from the OpenCV (library for image processing) and Qt framework (framework for C++).

The class diagram¹ in 5.1 show mainly classes of my task. The *mainly* methods located in the `ImageViewer` class, where contains all functions of the software. To represent the information of image and preprocessing about clear the yellow grid, we use the classes such as `Line`, `Edge`, `Landmark`, `YellowGird`, `Image` class. For the edge segmentation, construct the pairwise geometric histogram, probabilistic hough transform and landmarks detection, we have `GFeatures`, `LocalHistogram`, `ShapeHistogram`, `EdgeSegmentation`, `PHTransform` `LandmarkDection` class. The main functions were inherited from the abstract classes `HistogramMethod`, `SegmentMethod`, `HoughMethod`, `LandmarkMethod` respective and used in main class (`ImageViewer`) via the `Sceneario` class.

5.2 Image preprocessing

The *Image processing* section describes the information about the classes which describe the geometric objects can be represent the image and the method to remove the yellow grid on the images.

The `Line` class descibes the information of a straight line and its method, such as: get the

¹See the full image in Appendix

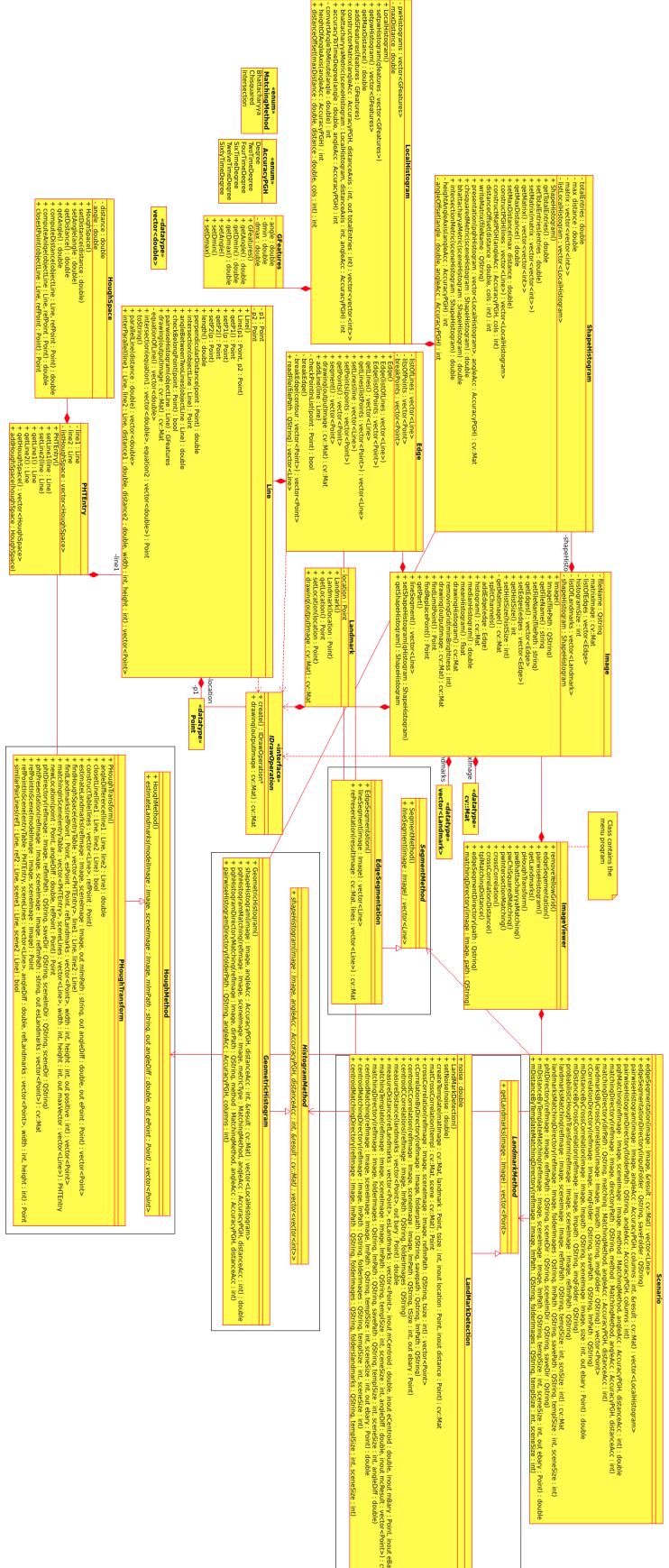


Figure 5.1: The class diagram diagram

length of line, compute the perpendicular distance from a point to line, find the intersection between two lines, compute the angle between two lines, find the parallel line with this line.

The **Edge** class used to presented for a curve and the methods with edge. An edge can be presented by a list of lines or a list of points. The important methods in **Edge** class are **breakEdge()** and **segment()** method. It used to break the edge into approximate lines based on the list of point constructed edge.

The **Image** class presented the information of an image such as file name, list of edge extracted from it. Besides, **Image** class also provides the methods to get the file name of image, compute the histogram of image, remove the yellow grid (if it exist) on image, get the PGH² of image, read its landmarks from a file, etc.

5.3 The abstract classes

The abstract classes contains the abstract methods get the actions on image such as segmentation, PGH construction,... The methods were implemented by the inherit classes, respective and provide the way access to action for other classes. The abstract classes include: **HistogramMethod** class, **SegmentMethod** class, **HoughMethod** class, **LandmarkMethod** class.

5.4 Edge segmentation

Edge segmetation includes the classes used for segment an image. Besides the classes construct the edge which described in previous section such as **Line**, **Edge**,..., we also provide the access method for another classes.

The **EdgeSegmentation** class provides the methods such as obtain the lines from an image, presentation the result after segmentation or applying the segmentation on an images folder.

The methods in **Edge segmentation** are:

- Extract the approximate lines of object in an image
- Extract the approximate lines of object in each image in a folder

²Pairwise geometric histogram

5.5 Construct pairwise geometric histogram

This section describes the classes used for PGH constructed process.

`GFeatures` class contains the relative information of the objects in PGH such as angle, minimum distance and maximum distance. It provides the methods to get and set the relative information.

`LocalHistogram` class constructed for containing the informations when computing the PGH of a line in object. The chosen lines as reference lines, the local histogram constructed based on recording the relative between reference line and other lines in object. Besides, it also have the methods help the user change the accuracy, such as the angle accuracy or distance accuracy.

`ShapeHistogram` class constructs the PGH for an object. It was constructing based on combine all PGH of the lines in object. It also provides the methods to compute the measure distance between the pairwise geometric histograms by a matching method. The methods in this class includes:

- Construct the PGH for an image
- Construct the matrix to save the PGH result
- Compute the measure distance between two PGHs based on *Bhattacharyya*, *Chi-Squared* or *Intersection* metric

`GeometricHistogram` class provides the access ways for another classes. By this class, the user can compute the pairwise geometric histogram of an image and calculate the distance between the pairwise geometric histograms.

5.6 Estimate the global pose

This section describes the classes use probabilistic hough transform to estimated a model image in a scene image. In particular is estimating the reference landmarks on the scene image.

`HoughSpace` class contains the information about angle and distance from a line to a reference point. These information recorded to construct the accumulator when we apply the probabilistic hough transform.

`PHTEntry` class present for each entry when constructing the reference table in training process. Each entry contains the pair of lines and its information about angle and distance to a reference point.

`PHoughTransform` class describe the main process when we apply the probabilistic hough transform to estimate the landmarks. It includes the methods to construct the reference table, find the reference point in scene image and estimate the landmarks. Besides, it also provides the methods to estimated the landmarks of an image on directory of images.

5.7 Refine the landmarks

`LandmarkDetection` class provides the methods to refine the landmarks. It use cross-correlation technique to refine the estimated landmarks. Besides, we also can compute the centroid point of object.

Chapter 6

Result

6.1 Experimentations

The experimentation based on a machine equipped with Intel(R) Core(TM) i7-4790 CPU 3.6GHz, 16 GB of RAM. The testing data is two set of biological images: *Right mandible and left mandible*. For each dataset, it includes 293 images(3264 x 2448). However, the data was filtered by suppressing the bad images in both dataset. The bad images includes the empty images and broken images (image contains the broken object). They are showed as below:

- Md 004.JPG
- Mg 007.JPG
- Mg 248.JPG
- Md 146.JPG
- Mg 040.JPG
- Mg 292.JPG
- Md 238.JPG
- Mg 066.JPG
- Mg 003.JPG
- Mg 159.JPG

6.1.1 Parameters

In the program, we have used the parameters for the methods:

- The best segmentation obtained from choosing a good threshold value. In program, Canny algorithm used to segment the image. So, the ratio between *lower threshold* : *upper threshold* is important to get a good result. And the ratio used: 1 : 3 (in class `Image`, method `getEdges`), this ratio has been chosen experimentally. The lower value is $1 * threshold$ value and the upper value is $3 * threshold$ value. The *threshold* value has been identified by analysing the histogram of image.

- The angle and distance accuracy used in constructing the PGH matrix and calculate the measure distance between PGHs. The angle accuracy can be 90 ($0.5 * 180$), 180, 360 ($2 * 180$), 720($4 * 180$), 1080($6 * 180$), 2160($12 * 180$) degree. The distance accuracy can be 250, 500 or 1000 columns. The **default value** in program is **180** degree for angle accuracy, and **250** for the distance accuracy.
- During apply the Probabilistic Hough Transform, to save processing time during training, we just consider the pair of closet lines. And the parameters used to indicate the closet line are (used in method `closetLine`, class `PHoughTransform`):
 - Length of each line greater than **60** pixels
 - Angle between two lines greater than **15** degree
 - Perpendicular distance from one of two endpoints of a line to other line less than **5** pixel.

The conditions to predicate two pairs of lines are similar (used in method `similarPairLines`, class `PHoughTransform`):

- Subtraction between angle of two pair of lines is less than **1**
- Subtraction between ratio couple of scene lines and reference lines is less than **1**
- Subtraction between distance of two pair of lines is less than **2**
- The size of bounding box around reference landmarks used for estimating landmarks by cross-correlation method or compute the estimated centroid is **400** pixels (used in method `crossCorrelation` and `crossCorrelationDistance`, class `ImageViewer`)
- The size of bounding box around reference landmarks and estimated landmarks used to refine the estimated landmarks or compute the estimated centroid are **400** pixels and **1400** pixels, respective.(used in method `getLandmarks` and `tplMatchingDistance`, class `ImageViewer`) To increase the flexible of program, all parameters was placed in the resources files (**data/resources** folder). For each group parameters, it was putted in a file, it can be easy to manage.

6.2 Results

The automated landmark identification is examined on two data sets. And the landmarks are extracted: 18 landmarks for each *right mandible* image, 16 landmarks for each *left mandible*

image.

The accuracy of system can be determined by comparing the differences(in pixels) between the

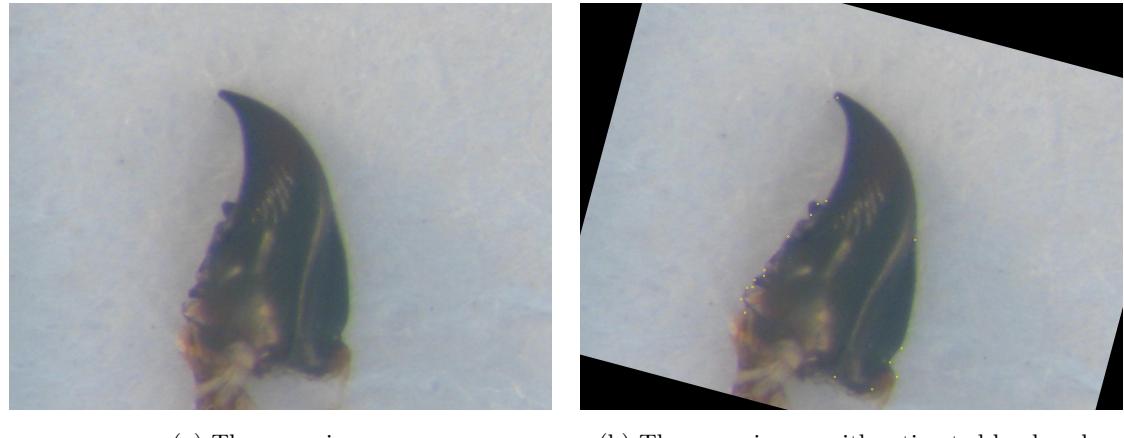


Figure 6.1: Automatic identification the landmarks

landmarks located by this method and the manual landmarks. Besides, this method includes several steps, the result of each step will effect on next steps. So, to evaluate the accuracy of this method, we can evaluate the result of each step.

Chapter 7

Conclusion

The landmarks are important characteristic used in shape analysis of many biological and medical application. The method proposed in this thesis can be used to estimate the landmarks on biological image. These estimated landmarks can be compared with the result estimated by cross-correlation.

After finishing the internship, we have done to implement the proposed method by using the OpenCV library and the Qt framework on C++. And the testing was finished on two set of biological images: *right mandible and left mandible*. A feature work could be apply this method on the other dataset of biological images.

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