

Facial Expression Recognition using Local Binary Patterns

with classification based on Support Vector Machines



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Abstract:

Since the last decade, a lot of researches have been carried out about emotion recognition. The number of projects conducted in this field demonstrates the interest and the importance of systems which can recognize human mood.

In this project, an emotion recognition system is developed, using a Microsoft Kinect. This recognition is achieved in 3 steps: Face detection, extraction and classification of facial features, this structure being the usual *modus operandi* in emotion recognition research.

Face detection is performed using Viola-Jones' algorithm, then Local Binary Patterns (LBP) are used to extract facial features. Finally, Support Vector Machines (SVM) classify these features into six predefined emotions.

The system is implemented to run on a computer using a Kinect and works for one person in front of it. The classifier is trained with the Karolinska Directed Emotional Faces database, which includes enough different faces to obtain a satisfying result.

Preface

This report documents the semester project entitled *Facial expression recognition using Local Binary Patterns*. The project was carried out during the 9th semester of specialization *Vision, Graphics, and Interactive Systems* under the Department of Electronic Systems at Aalborg University in Autumn 2012.

The report is divided into four parts plus appendices: *Introduction*, *Feature Detection*, *Feature Classification*, *Implementation* and *Evaluation*. The first part review the general structure of a facial expression recognition system and its main issues, and concludes with a state of the art of existing systems. Analysis of possible solutions and design of our system are contained in the following two parts, and the fourth part describes our implementation. The last part evaluates the performance and accuracy of our system and concludes on the project as a whole.

References to secondary literature sources are made using the syntax [number]. The number refers to the alphabetically sorted bibliography found at the end of the report, just before the appendices.

We would like to thank our supervisor at Aalborg University Zheng-Hua Tan for supporting us in this challenging project.

A CD is attached to this report which includes:

- Source code of the developed program.
- PDF file of this report.

Aalborg University, December 4, 2012

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Part I

Introduction

Contents

The main motive of this project is to understand facial expression recognition systems and their applications. A review of the architecture of such systems will be done, along with a state of the art of already existing algorithms. After this study, issues coming along with this kind of recognition system will be studied. In the last part, the requirements of this project will be formulated.

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Chapter 1

Motivations

A facial expression is a "visible manifestation of the effective state, cognitive activity, intent, personality, and psychopathology of a person" [8]; facial expressions represent a huge part in dialogue and interaction with other humans. Indeed, facial expressions carry more informations than speech, informations on which humans can relay for interaction. Facial expressions have a considerable effect on a listening interlocutor; in a conversation, it represents 55 percent of information received by a listener, while 38 percent are conveyed by voice intonation and the remaining 7 percent by the spoken words [21].

Since Antiquity, researchers have been interested in emotion and more particularly in emotion recognition. One of the most important studies on facial expression analysis impacting on modern day science of automatic facial expression recognition is the work carried out by Charles Darwin [4]. In 1872, Darwin wrote a book that established general expression principles, expression means and expression description for both humans and animals [6]. He also classified various kinds of expressions. This can be considered as the beginning of facial expression recognition.

Nowadays, with the emergence of new technologies and computers, research is now focused on computer-based automatic facial expression recognition. Because facial expressions are major factors in human interaction, this research field will improve the domain of Human-Machine Interaction. Indeed, emotion recognition will enable computers to be more responsive to users' emotions, and allow interactions to become more and more realistic.

Another domain where facial expression recognition is an important issue is robotics. With the advances made in robotics, robots tend to mimic human emotion and react as as human-like as possible, especially for humanoid robots. Indeed, since robots are being more and more present in our daily lives, they need to understand and recognize human emotions.

A lot of applications in the robotics field have already been created. For example, Bartlett et al. have successfully used their face expression recognition system to develop an character that is animated and that mirrors the expressions of the user (called CU Animate) [3]. They have also been successful in deploying the recognition system on Sony's Aibo Robot and ATR's RoboVie [3]. Another interesting applica-

tion has been demonstrated by Anderson and McOwen, called "EmotiChat" [2]. It is a regular chatroom, except the fact that their facial expression recognition system is connected to the chat and convert the users' facial expressions into emoticons. Because facial expression recognition systems' robustness and reliability are constantly increasing, lots of innovative applications will appear.

There are also various other domains where emotion recognition can be used: Telecommunications, behavioural science, video games, animations, psychiatry, automobile safety, affect-sensitive music jukeboxes and televisions, educational software, etc [4].

This project focuses on facial expression recognition from a video stream. Indeed, facial expression recognition can be performed *statically* on input images, or *dynamically* on video sequences. Systems can also be *obtrusive*, or *non-obtrusive*, the former based on a device mounted on the user's head or body, therefore following each of his movements and perform facial expression recognition without much losses, while the latter can encounter difficulties if the user is not properly situated. However, non-obtrusive systems allow more natural user interactions. We chose our system to be non-obtrusive, and will detail its setup further in the next section.

1.1 Environment Setup

Our system will use the camera embedded into a Microsoft Kinect to record the user's video input. We will consider a casual use of the camera, the user sitting in front of the computer, the camera being next to it, as seen in **Insert picture of the setting & ref to figure**. This camera provides a 640×480 pixels frame resolution, while recording at 30 FPS.

For development and training purposes we will use some pre-existing emotion datasets, in order to validate the efficiency of the system before testing it in real conditions.

1.2 Facial Expression Datasets

Databases are very important for facial expression recognition system.

Using the same databases as in previous studies allows performance and accuracy comparisons between new implementations and previously obtained results. Since most studies draw their results on the same databases, it is then relatively easy to compare them and choose a database suitable for our system.

Databases are however difficult to build. Indeed, it has to be obtained following a meticulous procedure while being exhaustive so it can be considered as representative. The majority of actual databases use posed expressions rather than spontaneous ones, this choice having a major influence on facial expression recognition systems. This explains why some databases are updated, and now integrate spontaneous expressions. Even with this transition from posed expressions to spontaneous expressions, there are other requirements that should be met to have a standardized database. Its content should be of different resolutions and scales, and should also contain exposition under different conditions, i.e changes in lightning, occlusions or different head angles [4].

Constructing a database is then a tedious task because of all these requirements to meet. Consequently, most studies are based on already existing datasets. The 3 datasets described afterwards are popular and freely available facial expression datasets which have been used a numerous amount of times in the past few years. Our system will then be trained and tested with one or several of these databases.

1.2.1 Japanese Female Facial Expression Database (JAFPE)

This database contains 213 images of 7 facial expressions (6 basic facial expressions: happy, angry, afraid, disgusted, sad, surprised, and 1 neutral facial expression). Each expression has been photographed three or four times. Each image has been rated on 6 emotion adjectives by 60 Japanese subjects. All images come from 10 Japanese female models. The database was planned and assembled by Miyuki Kamachi, Michael Lyons, and Jiro Gyoba [17].

This database contains only posed expressions. The photos have been taken under strict and controlled conditions: similar lighting and hair tied so there is no facial occlusion [4].

An example of images contained in the database is given by Figure 1.1. In this figure, this is a female subject displaying 7 different emotional expressions (neutral, happy, angry, afraid, disgusted, sad, surprised).

1.2.2 Karolinska Directed Emotional Faces Database (KDEF)

The Karolinska Directed Emotional Faces (KDEF) contains 4900 pictures of human facial expressions. The material was developed in 1998 by Daniel Lundqvist, Anders Flykt and Professor Arne Ohman at Karolinska Institutet, Department of Clinical

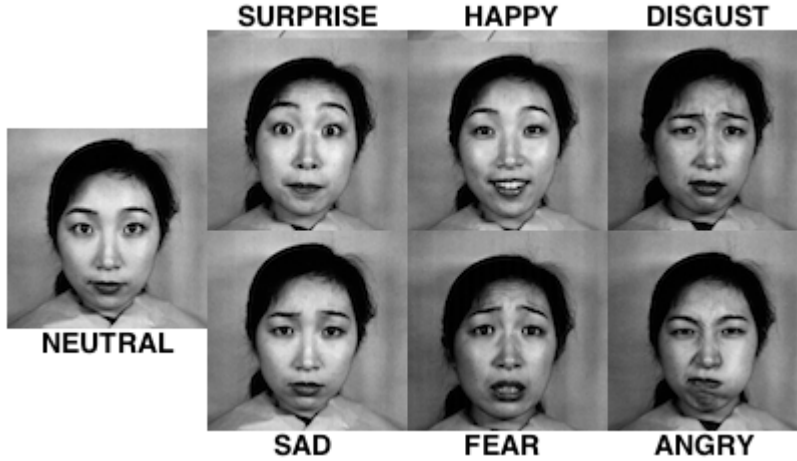


Figure 1.1: Example of images from JAFFE database

Neuroscience, Section of Psychology, Stockholm, Sweden [14].

The database was first developed for psychological and medical research purposes. It was created so it could be used in perception, attention, emotion, memory and backward masking experiments. This database has also been built under controlled conditions. Indeed, researchers tried to maintain constant and soft lighting for each subject. Furthermore, they made their subjects wear the same grey T-shirts, and used a grid to center the participants' faces while they were shot. This grid was also used to place eyes and mouths at the same position in fixed image coordinates during scanning [14].

The database contains 70 individuals (35 males and 35 females), from 20 to 30 years, each one displaying 7 different emotional expressions (neutral, happy, angry, afraid, disgusted, sad, surprised). Each expression has been photographed (twice) from 5 different angles (-90, -45, 0, +45, +90 degrees: i.e. full left profile, half left profile, straight, half right profile, full right profile) [14].

An example of images contained in the database is given in Figure 1.2 which represents a female subject photographed from a straight angle and displaying 7 different emotional expressions (neutral, happy, angry, afraid, disgusted, sad, surprised).

1.2.3 Montreal Set of Facial Displays of Emotion Database (MSFDE)

This database contains facial expressions of European, Asian, and African subjects, from both genders. Each expression was created by directly asking the subject to

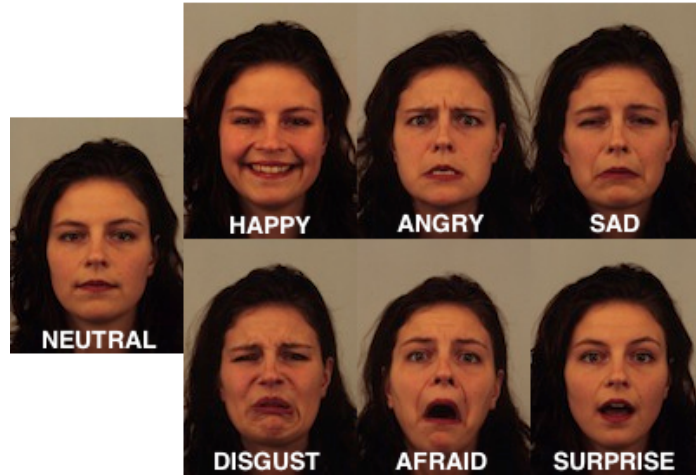


Figure 1.2: Example of images from KDEF database

express this emotion [28].

The database contains expressions of happiness, sadness, anger, fear, disgust, and embarrassment, along with a neutral facial expression. All expressions have been photographed at 5 different levels of intensity [28].

An example of images contained in the database is given in Figure 1.3, where an African female subject displays 7 different emotional expressions (neutral, happy, angry, afraid, disgusted, sad, ashamed).



Figure 1.3: Example of images from MSDFE database

Chapter 2

Facial expression recognition

After having stated the conditions and motivations of this project, we will now describe the general structure of a facial expression recognition system. It can indeed be roughly summed up as classification applied to a pre-processed image. An overview of pre-processing steps will be done in this chapter, while feature extraction and classification will be more detailed respectively in Parts 5 and 7. Following sections will be about issues raised by facial expression recognition systems, and key requirements these systems have to meet in order to be considered acceptable.

2.1 General structure

«««< HEAD Facial expression recognition is a system enabling an automatic recognition of emotions displayed by a human face. Facial expression recognition can be image or video-based; it can also be computed in real-time if needed. Researchers usually try to recognize emotions out of static images. It can also be achieved real-time on video streams : While the person displays his/her emotions, the facial expression recognition system analyses the video, and detect the displayed emotion. ===== Facial expression recognition is a system enabling an automatic recognition of emotions displayed by a human face. Facial expression recognition can be image or video-based; it can also be computed in real-time if the system needs it. Researchers usually try to recognize emotions out of images of human faces. This can also be achieved real-time on video streams : While the person displays his/her emotions, the facial expression recognition system analyses the video, and detect the displayed emotion. »»»> b610ac62028e14055893b066f33d934c6a720cdd

In both cases, facial expression recognition process is structured as in Figure 2.1

2.1.1 Image Acquisition

The first step is "Image Acquisition". Images used for facial expression recognition can be static images or image sequences, with the latter giving more informations about the displayed expression, i.e steps in muscles movement. About static images, facial expression recognition systems usually take 2D greyscale images as inputs. We

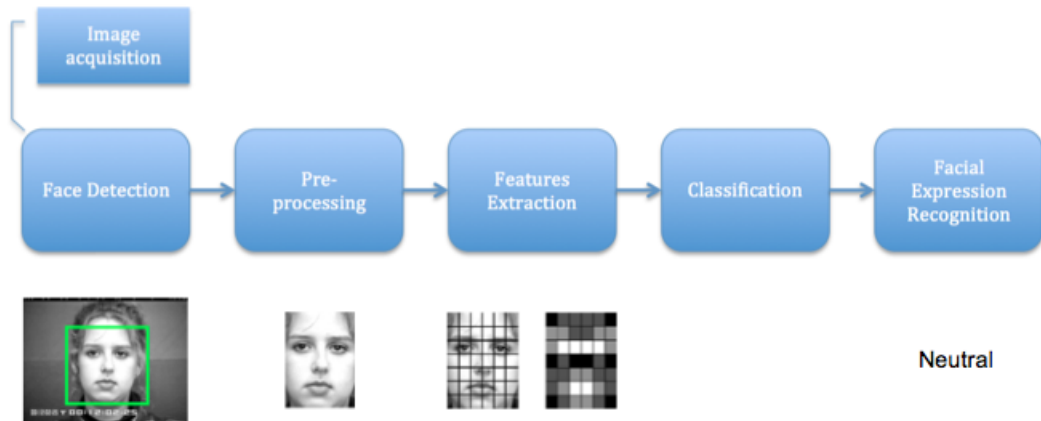


Figure 2.1: Facial Expression Recognition process

can however expect future systems to use color images; first because of the increasing affordability of technologies and devices capable of capturing images or image sequences; then because colors can give more information on emotions, for example blushing [5].

2.1.2 Face Detection

«««< HEAD Second step is "Face Detection". Indeed, in a static image and even more in an images sequence, this is an obvious need. Once the face has been detected, all other non-relevant information can be deleted. This step could hence be included in the next step, which is "Pre-processing", but because of its importance it can be considered as a step in itself. If working with image sequences or video streams, the face has to be detected and tracked. One of the most used and famous detection and tracking algorithm is the Viola-Jones algorithm, which will be explained further in Chapter 4. This algorithm can be trained to detect all kind of objects, but is mostly used for face detection. ===== Second step is "Face Detection". Indeed, in a static image and even more in an images sequence, this is an obvious need. Once the face has been detected, all other non-relevant information can be deleted, since only the face is needed. It could hence be included in the next step, which is "Pre-processing", but because of its importance it represents a step in itself. In facial expression recognition system working with image sequences, the face has to be detected, but also tracked. One of the most used and famous detection and tracking algorithm is the Viola-Jones Algorithm, which we will explain in detail later in this report. This algorithm can be trained to detect all kind of objects, but is

mostly used for face detection. »»»> b610ac62028e14055893b066f33d934c6a720cdd

2.1.3 Pre-processing

Third step is "Pre-processing", where image processing algorithms are applied to the image in order to prepare it for the next step. Pre-processing is usually about noise removal, normalization against the variation of pixel position or brightness, segmentation, location or tracking of parts of the face. Transformation, scaling and rotation of the head in the image or image sequence have an effect on emotion recognition. In order to solve this problem, the image can be geometrically standardized, with the eyes generally used as reference points [5].

2.1.4 Feature Extraction

Once the image has gone through the "Pre-processing" step, the next one is "Feature Extraction". In this step, data is converted "into a higher representation of shape, motion, color, texture, and spatial configuration of the face or its components" [5]. One of the main goals of this step is to reduce the dimensionality of the input data. The reduction procedure should retain "essential information possessing high discrimination power and high stability" [5]. There are a lot of features extraction methods. The most famous are : Principal Component Analysis (PCA), Linear Discriminant Analysis (LDA), Problem Based Learning (PBL), Hidden Markov Models (HMM), Eigenfaces, Gabor Wavelets. This step will be detailed further in Part 5. The extracted data is then used in the "Classification" step.

2.1.5 Classification

The classification step is the culminating point of the facial expression recognition process. There are many kinds of classification algorithms, some of them can even be used in the feature extraction part, as it will be detailed in Part 5. This step takes into input a model previously trained with pre-processed data, and test data made of feature vectors extracted from the image we want to label. Feature vectors from pre-processed data and test data have to be obtained using the same feature extraction algorithm. The chosen classifier then outputs a value corresponding to the label of the class the picture belongs to.

2.2 Issues

2.2.1 Datasets

Databases can be a source of issues. As said previously, databases should meet a number of requirements in order to be as exhaustive and efficient as possible.

In order to build a facial expression recognition system efficient in live conditions,, it should be able to recognize spontaneous expressions rather than posed expressions. Indeed, spontaneous expressions are closer to reality than posed expressions, the latter being exaggerated to facilitate their labelling and recognition. While creating a database of spontaneous expressions, Sebe and al [24] made some observations of the major problems they encountered [4]:

- The same emotions can be expressed at different intensities by different subjects;
- As soon as the subject is aware of being photographed and studied, the authenticity of the emotion is lost;
- Because of the laboratory conditions, even if the subject is not aware of being photographed or recorded, the subject is not encouraged to display spontaneous expressions.

In order to overcome these problems, they came up with a method. Their solution was to record facial expressions with a camera hidden in a video kiosk displaying emotion inducing videos. Subjects were notified of the recording after it was done, and were asked a permission to use recorded sequences for research studies. The subjects then explained which emotions they felt and expressed, their replies being documented even if it did not match the recorded expressions [24].

The researches found that a wide range of expressions are hard to induce, particularly fear and sadness. They also found that spontaneous expressions could be misleading: some subjects express one emotion while feeling another one (for example, one subject was showing sadness while being happy) [24].

In a nutshell, databases bring some issues that can affect the authenticity of the recognition system. It depends of the type of expressions: spontaneous or posed expressions. If the system aims to recognize facial expressions of people unaware of it, spontaneous expressions databases will be used but, as seen previously, it can lead to authenticity issues. If the system aims to recognize facial expressions of people asked to express certain emotion, posed expressions databases will be used, but the result will not be close to reality.

2.2.2 Real-time

«««< HEAD The primary goal of the facial expression recognition system described in this paper is to perform real-time facial expression recognition. As a real-time application, the processing time should be taken into account. Indeed, if it is too long, the system will not be responsive enough to be labelled as real-time.

This is one of the challenges of this kind of system, because processing is usually really heavy no matter which algorithm is used. Most facial expression recognition applications should be working in real-time conditions, for example in robotics or in surveillance. A solution could be to find new algorithms for Facial Expression Recognition or to improve and lighten already existing algorithms. ===== The primary goal of the Facial Expression Recognition system describer in this paper is to perform real-time facial expression recognition. As a real-time application, the processing time should be taken into account, since if it is too long the application won't be responsive enough to be labeled as real-time.

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2.2.3 Conditions

Another one of the challenges of this kind of system is to be independent of recording conditions. It means that the recognition should not be disturbed for example by occlusions, or difference in the lighting, or even by the angle between the face and the camera. These examples cover almost all conditions that can change during the recording, and have an influence on the recognition system.

Occlusion

"Occlusion" defines all elements covering the face, partly or entirely. For example, a beard, a scarf masking the bottom of the face, glasses or bangs. By hiding a part of the face, these occlusions can affect the recognition. Indeed, facial expression recognition systems are based on comparison of features, and if all the features cannot be compared because something is covering a part of the face, the recognition accuracy is affected. In order to compensate for this problem, some databases includes data

with occluded faces, for example with beards, glasses or scarves. This is the case for the AR Face database. Some examples of images contained in this database are given by Figures 2.2 and 2.3 [18].



Figure 2.2: Example eye occlusion in the AR Face database



Figure 2.3: Example of face occlusion in the AR Face database

Lighting

As for occlusion, lighting is an element that can affect recognition effectiveness. With different lighting conditions from those in the database, recognition will be less efficient. All conditions different from those recorded in the database on which the recognition process is based will impact the system. If images are brighter or darker than reference data, some details can disappear, or some features will not be recognized as well as if the conditions were identical. In order to compensate for this problem, databases can include data with different lighting conditions. This is the case for the AR Face database and an example of the images contained in this database is given by Figure 2.4 [18]:



Figure 2.4: Example of different lighting conditions (from left to right: dark to bright) in the AR Face database

Angle

Head angle is one of the most impacting conditions during recognition. Indeed, some features can be occluded or disappear if the head does not properly face the camera. This issue also rises if the system is not tuned to work with head angles other than straight profile. For example, with a profile angle, one eye, half of the nose and of the mouth disappear. If the database does not contain samples with profile faces, the recognition will fail. However, if the database contains images from straight angle as well as from different profile angles, recognition will be possible. An example of different images taken from different angles for one emotion, "Fear", from the KDEF database is given in Figure 2.5:

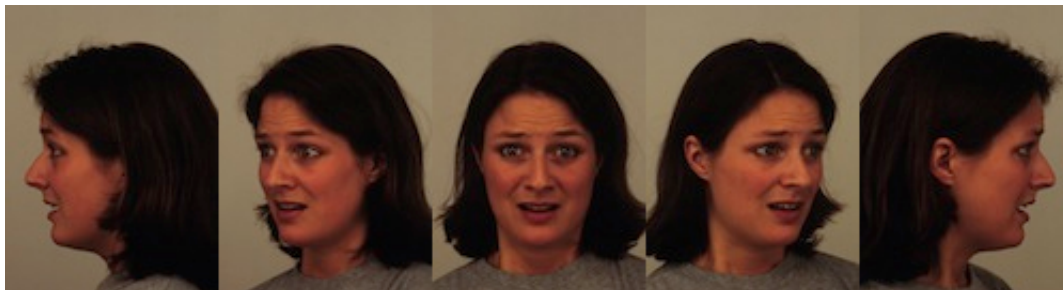


Figure 2.5: Example of different angles for the "Fear" emotion (from left to right: full left profile, half left profile, straight, half right profile, full right profile) in the KDEF database

2.3 Requirements

Based on everything said previously, our facial expression recognition system can be defined by some requirements prior to its implementation. Additional requirements may be defined further. Here are the requirements already defined :

- Able to recognize basic emotions : As explained before, facial expression recognition systems are able to recognize 6 basic emotions and the neutral state. This system should be able to do the same: recognize the 6 basic emotion that are "Happiness", "Fear", "Surprise", "Disgust", "Sadness", "Anger" and the neutral state.
- Able to work in real-time : «««< HEAD This system should be able to recognize facial expressions in real-time. It means that it can recognize expressions based on a video sequences. It also means that the algorithm for the feature extraction has to be carefully optimized so it is able to compute facial features in a decent amount of time. ===== This system should be able to recognize facial expressions in real-time. It means that it can expressions based on a video sequences. It also means that the algorithm for the feature extraction has to be carefully optimized so it is able to compute facial features in a decent amount of time. »»»> b610ac62028e14055893b066f33d934c6a720cdd
- Recognition from straight angle of the face : This system should be able to recognize facial expression from a straight angle of the face. It means that the system should be able to detect faces in front of the camera lens, and recognize expressions in these faces. It might not be able to recognize emotions on a face on a profile or half-profile angle.
- Recognition with no occlusion : This system should be able to recognize emotions with no occlusion on the subject's face. It means that the face should not be covered in any way: no glasses, no beard or no scarf. The face should also be complete, not cut and not masked.
- Recognition with no changes in lighting : This system should be able to recognize emotions under constant lighting conditions during the recognition process. Moreover, the intensity level of the light should be as close as possible to the one of the database. This way the lighting would not have any influence on the recognition process.

Part II

Feature detection

Contents

Before getting to the main part of this project which is Feature extraction, there is a mandatory step that is Feature detection. In order to avoid as much computation and processing as possible, only parts containing regions of interest for a Facial Expression Recognition system have to be processed. It consequently means that detection of interesting features has to be performed beforehand, which is the goal of face detection. This part will explain how face detection works in general. We will then introduce the Viola-Jones algorithm, a performant and cost-effective method for face detection and tracking.

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Chapter 3

Face detection

Face detection is the first step following image acquisition, and is compulsory for facial expression recognition. At the end of this step, only useful information will remain. It will not only reduce processing time during the feature extraction step, but will also improve the classifier by discarding useless information.

3.1 Detection

Detection is finding out if the input image or video sequence represents or contains a particular object, usually followed by recognition. In our system, facial expression recognition will be performed. However, depending on the recognition, an additional tracking step can be needed. Tracking consists in following a moving target along the images of a video sequence [7].

An object detector can be defined as a "black box" taking an image as input. Its input depends on the type of detector, whether it is high level or low level. At a high level the output can be considered as an annotated image saying where the object of interest appears [7]. For example, the output can look like Figure 3.1 [7].

At a low level, the output is not an annotated image anymore. The core of the object detector is a basic component saying if an instance of the object of interest is contained in a certain region or sub-region of the original image. This kind of detection is performed by a binary classifier [7]. There is an example of a binary classifier output in Figure 3.2 [7].

3.2 Classifiers

Classification aims to solve the problem of identifying in a set of categories or sub-populations to which a new observation belongs. It is based on a training set of data that contains instances whose category affiliations are known. Data can be labeled based on some measures of inherent similarity; for example, vectors representing the



Figure 3.1: Example of an output of face detection

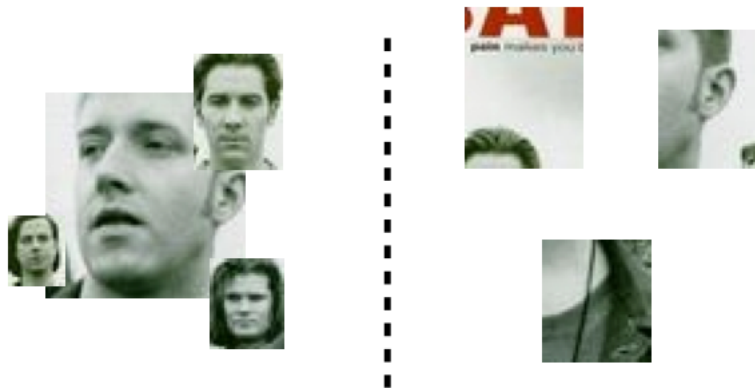


Figure 3.2: Example of a binary classifier output for face detection

distance between instances [32].

Chapter 4

Viola-Jones Face detection

Viola-Jones algorithm is "a visual object detection framework that is capable of processing images extremely rapidly while achieving high detection rates". 3 main points characterize this algorithm. The first one is the use of what is called an "integral image", which is a new representation of the image allowing the features to be computed very quickly. Second point is the use of a learning algorithm based on AdaBoost, which builds efficient classifiers. The third and last point is the use of a method to combine classifiers. This method combine classifiers in "cascade". It allows to focus on the promising object-like regions by discarding the background in a very quick way [31].

4.1 Overview

The Viola-Jones algorithm works as following [7]:

- This algorithm is a "strong, binary classifier built of several weak detectors"
- "Each weak detector is a simple binary classifier"
- During the learning part, a cascade of weak classifiers is used and trained in order to reach the desired hit/miss rate using AdaBoost learning algorithm
- The input image is then divided into several rectangular sub-regions in order to detect objects. Each sub-region is computed by the cascade of classifiers;
- To classify a sub-region as "positive", it has to pass all stages of the cascade
- The algorithm iterates over the 2 last steps with sub-regions of different sizes.

4.2 Haar features

The features used by Viola and Jones are based on Haar wavelets, which are single wavelength square waves. A square wave is composed of a high interval and a low

interval. In a two dimensional space, a square wave is represented by a pair of adjacent rectangles: a light one and a dark one. True Haar wavelets are however not used in rectangle combinations for visual object detection. There are better suited features for this task, which are Haar-like, hence the name of Haar (or Haar-like) features, instead of Haar wavelets [11].

Figure 4.1 shows some of the first Haar features in the original Viola-Jones cascade [11], while Figure 4.2 is an example from the extended set of features [7]. Figure 4.3 is an example of an early stage in the Haar cascade. In these examples, each pair of black and white rectangles represents a feature. These features are used by the algorithm to detect regions of interest in the input image [10].



Figure 4.1: Examples Haar features

Basic subtraction is used to detect the presence of Haar features. It consists of subtracting the average pixel value of the dark region from the average pixel value of the light region. There is then a thresholding of the result, where the feature is considered present if it is above the threshold. If the outcome is positive, the current stage is validated, and the feature can go on the next stage [11]. There are about 20 to 30 different stages in order to detect the presence of Haar features. The first stage is a very coarse scan of the image, while following stages are more finely tuned and harder to pass [10].

For example, Figure 4.4 shows a later stage in the Haar cascade. Compared to an earlier stage as in Figure 4.3, there are many more patterns of black and white rectangles that need to match the input image [10].

There are 3 kinds of features used by Viola-Jones' algorithm: a two-rectangle feature, a three-rectangle feature and a four-rectangle feature, as seen in Figure 4.5.

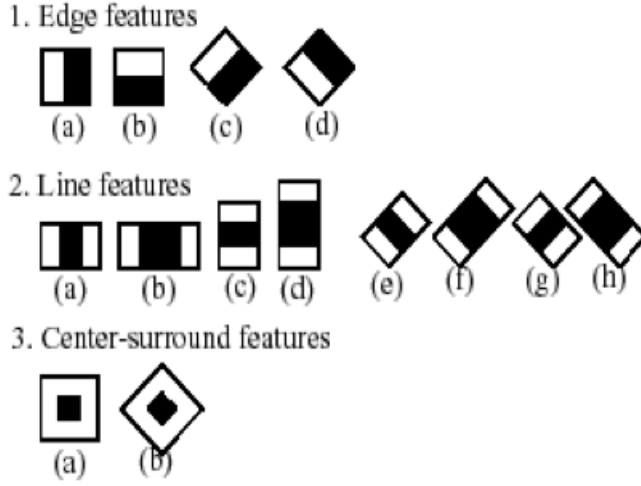


Figure 4.2: Extended set of features

Indeed, images (A) and (B) show the two-rectangle features, image (C) shows the three-rectangle feature, and image (D) shows the four-rectangle feature [31].

For two-rectangle features, the output value is computed by the difference between the sum of the pixels being in the two rectangular regions. The 2 regions are identical, with same size and same shape, and they are horizontally or vertically adjacent.

The three-rectangle feature value is calculated by the sum of the pixels of the two outside rectangles subtracted from the sum of the pixels in the central rectangle.

The last kind of feature is the four-rectangle feature, which value consists in the difference between the diagonal pairs of rectangles [31].

Viola and Jones admit that rectangle features can be considered as primitive features. In contrast with other features, rectangle features are quite coarse, even though they are sensitive to the presence of edges, bars and other simple image structure. It however appears that a rich image representation is provided by this set of rectangle features, and this representation supports effective learning. Compared to the great computational efficiency provided by rectangle features, their limited flexibility is then not much of a problem [31].



Figure 4.3: Example of an early stage in the Haar cascade

4.3 Integral image

Viola and Jones used an intermediate representation of an image called "integral image". This integral image allows a very fast computation of rectangle features [31], which then influences the determination of the presence or absence of hundreds of Haar features. In general, adding small units together is similar to integrating them; here, the small units are pixel intensity values. The integral value of a pixel can hence be computed by summing values from pixels above it and on its left. Integration of an entire image consequently starts at the top left corner and goes through all the image to the down right corner [11].

For a pixel P with coordinates (x, y) , its value in the integral image is computer as

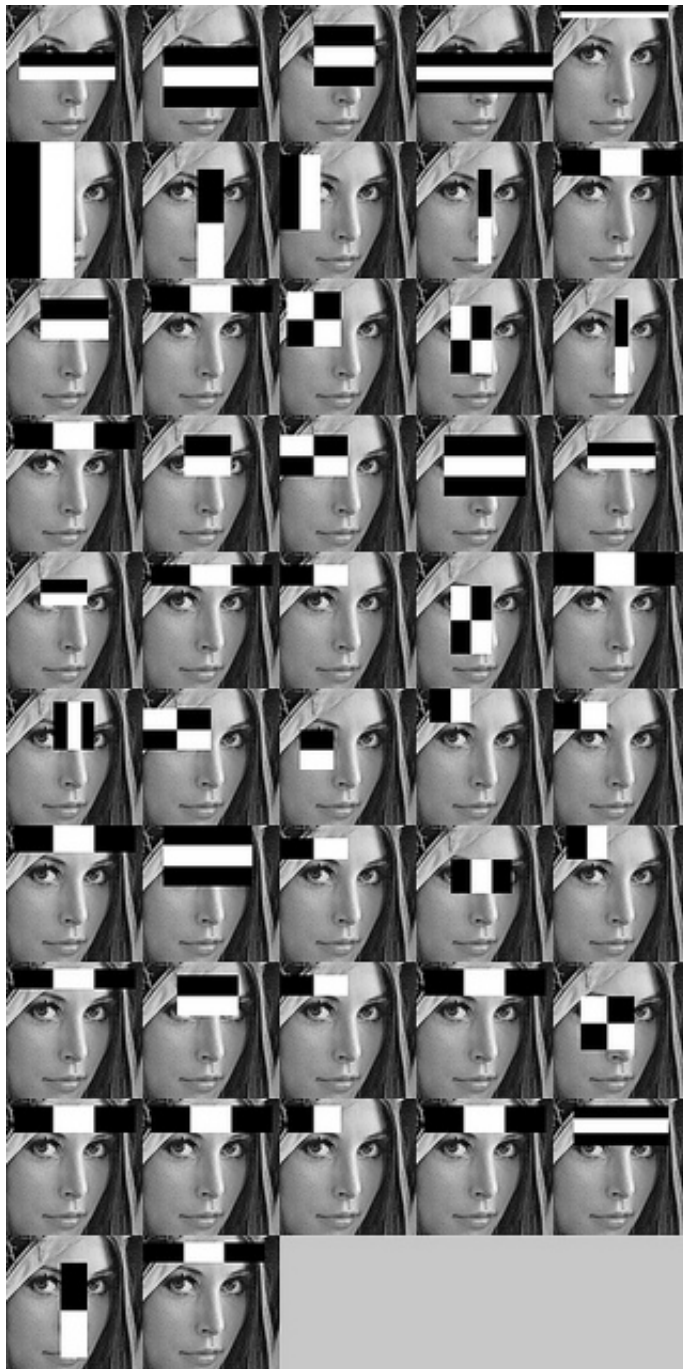


Figure 4.4: Example of a later stage in the Haar cascade

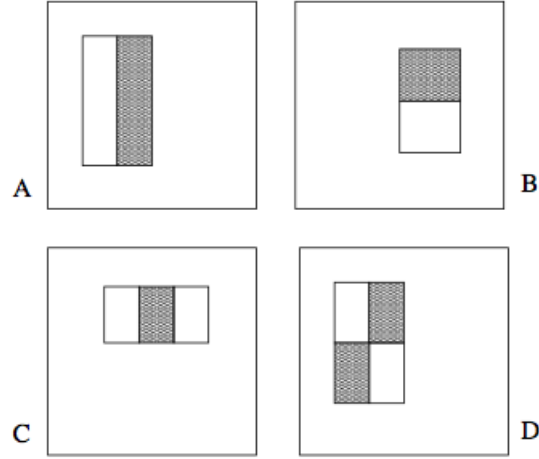


Figure 4.5: Example of the different kinds of rectangle features

follows:

$$ii(x, y) = \sum_{x' \leq x, y' \leq y} i(x', y')$$

where $ii(x, y)$ is the integral image and $i(x, y)$ is the input image intensity value function. In Figure 4.6, the value of the integral image at point (x, y) is represented as the sum of all pixels above and on its left [31].

Using the following pair of recurrences:

$$s(x, y) = s(x, y - 1) + i(x, y) \quad (4.1)$$

$$ii(x, y) = ii(x - 1, y) + s(x, y) \quad (4.2)$$

(where $s(x, y)$ is the cumulative row sum, $s(x, -1) = 0$, and $ii(-1, y) = 0$) the integral image can be computed in only one pass over the original image.

In Figure 4.7, the sum of the pixels in rectangle D can be calculated with four array references, thanks to the integral image. Value of the integral image at point 1 is the sum of pixels in rectangle A. Value at point 2 is $A + B$, at point 3 is $A + C$, and at point 4 is $A + B + C + D$. The sum in D can then be computed as $4 + 1 - (2 + 3)$ [31].

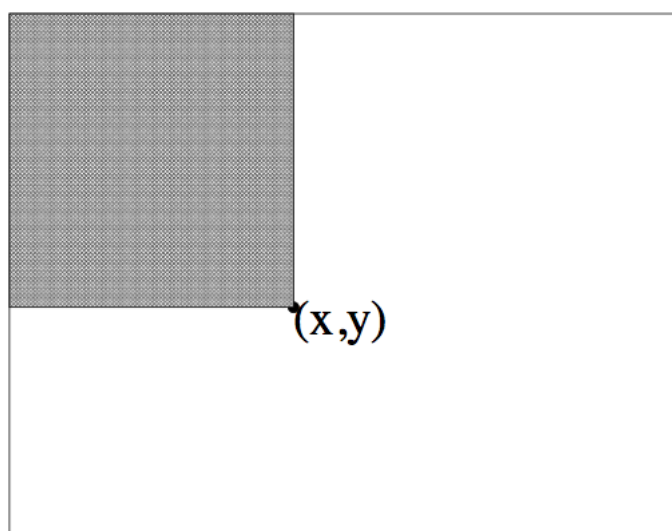


Figure 4.6: Integral image

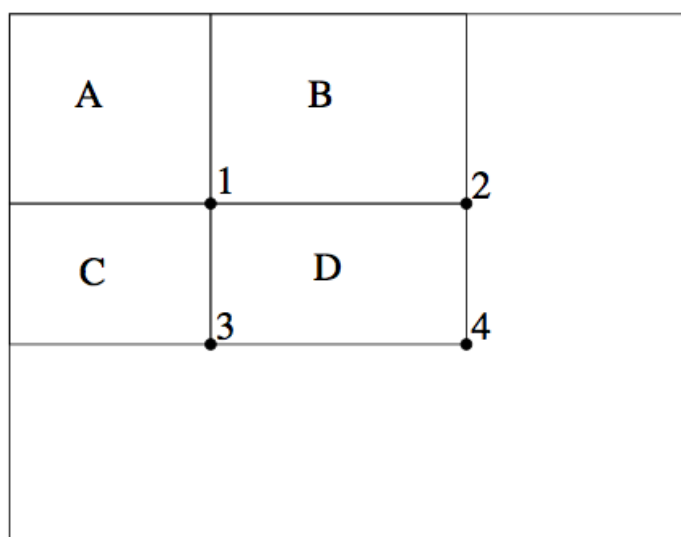


Figure 4.7: Integral image with four array references

4.4 Weak classifiers and AdaBoost

Features are extracted from a sub-region of an input image, which size is usually of 24×24 pixels. Each feature type is moved and scaled across the entire input image,

which means that there are about 160,000 possible combinations to process in a 24 pixel by 24 pixel sub-region [26].

AdaBoost is a machine-learning method used by Viola and Jones in order to select specific Haar features to use. It is also used to set the threshold levels. This method is based on the statement that the combination of many weak classifiers forms a strong one. They are called weak classifiers because their accuracy and efficiency are only a bit above random guessing, which is not particularly good. The purpose of using so many weak classifiers is to get a right answer with a higher rate of success. This algorithm relies on the verified hypothesis that if each weak classifier pushes the final answer a little bit in the right direction each time, it means the correct answer will be obtained in the end [11].

AdaBoost works the following way: it chooses a set of weak classifiers that are going to be combined and assigns a weight to each classifier (see Figure 4.8). The result of this weighted combination is a strong classifier [11]. One of the difficulties and challenges for this learning algorithm is to associate large weights to efficient classifiers, and smaller weights to each poor classifiers. In order to succeed in selecting a small group of good classifiers but with significant variety, AdaBoost is an aggressive algorithm [31].

Experiments have been conducted with a classifier built from 200 features and using AdaBoost. The classifier had a detection rate of 95%, and obtained only 1 false positive out of 14084 negative samples from the training dataset (see figure 4.9)[31].

This experiment, points out that a 200-feature classifier is an efficient technique for object detection. It also means that a boosted classifier constructed from rectangle features is an efficient technique for object detection. Although the results of this experiment are convincing in terms of detection, they may not be performant enough for real-world tasks. This boosted classifier requires 0.7 seconds to scan a 384×288 pixel image. Regarding the computation time, it is probably faster than any other existing system. In order to improve the system so that it will perform well in real-world conditions, detection performance must be improved. The most straightforward method to achieve that is to add features to the classifier. Doing that will immediately decrease the speed of this system; it will increase computation time [31].

4.5 Classifiers cascade

What Viola and Jones did to classify image regions and sub-regions in an efficient way is to combine AdaBoost classifiers as a filter chain. It is constructed as a cascade hence its name "Classifiers cascade". This chain is composed of a separate AdaBoost

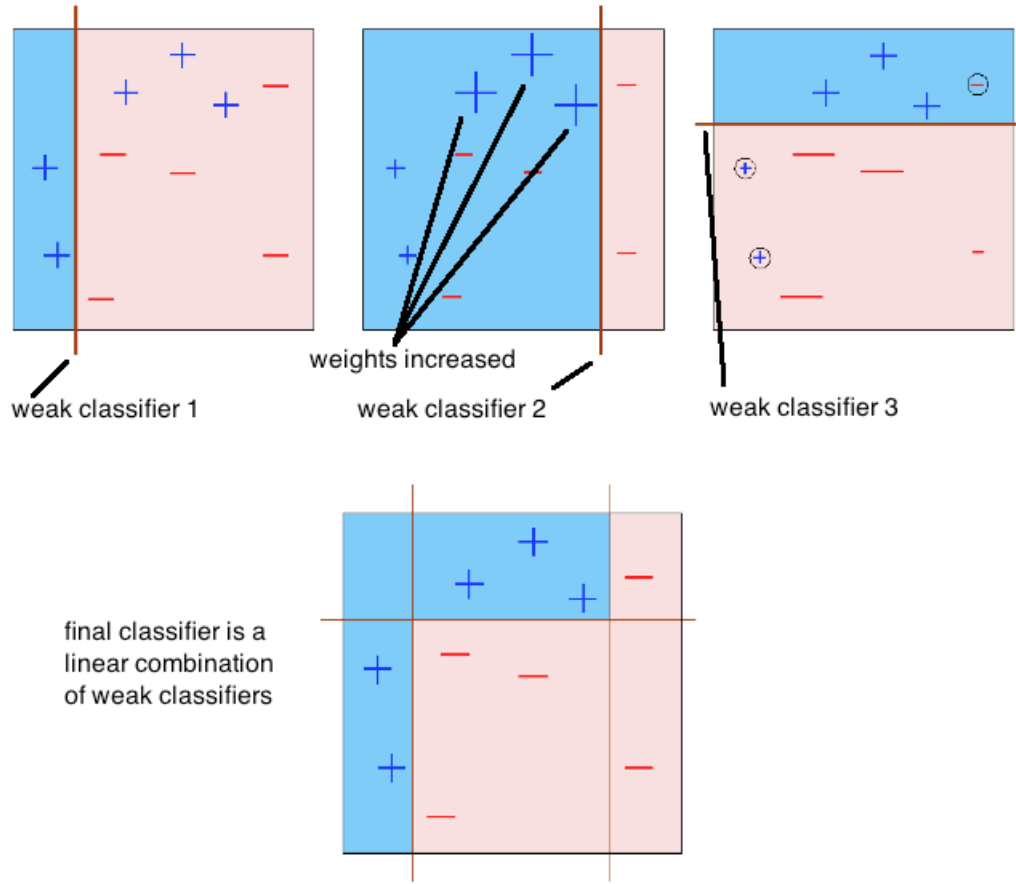


Figure 4.8: AdaBoost method

classifier for each filter, which has a fairly small number of weak classifiers. As in Figure 4.10, the classifier cascade represents a chain of filters. If an image sub-region passes successfully all cascade steps, it is labelled as "Face", otherwise it is classified as "Not Face" [11]. Using this algorithm with the classifiers cascade method allows to reduce significantly the computation time and increase significantly the detection performance [31].

Tests were conducted to see if the cascade method was feasible. Two simple detectors were trained, one of them being a 200-feature classifier and the other one being a cascade of 10 20-feature classifiers. Figure 4.11 gives the ROC curves comparing the two classifiers' performance. Between the two classifiers, regarding their accuracy, the difference is little and not significant. On the other hand, regarding their speed, the difference is large and significant, the classifier cascade being about 10

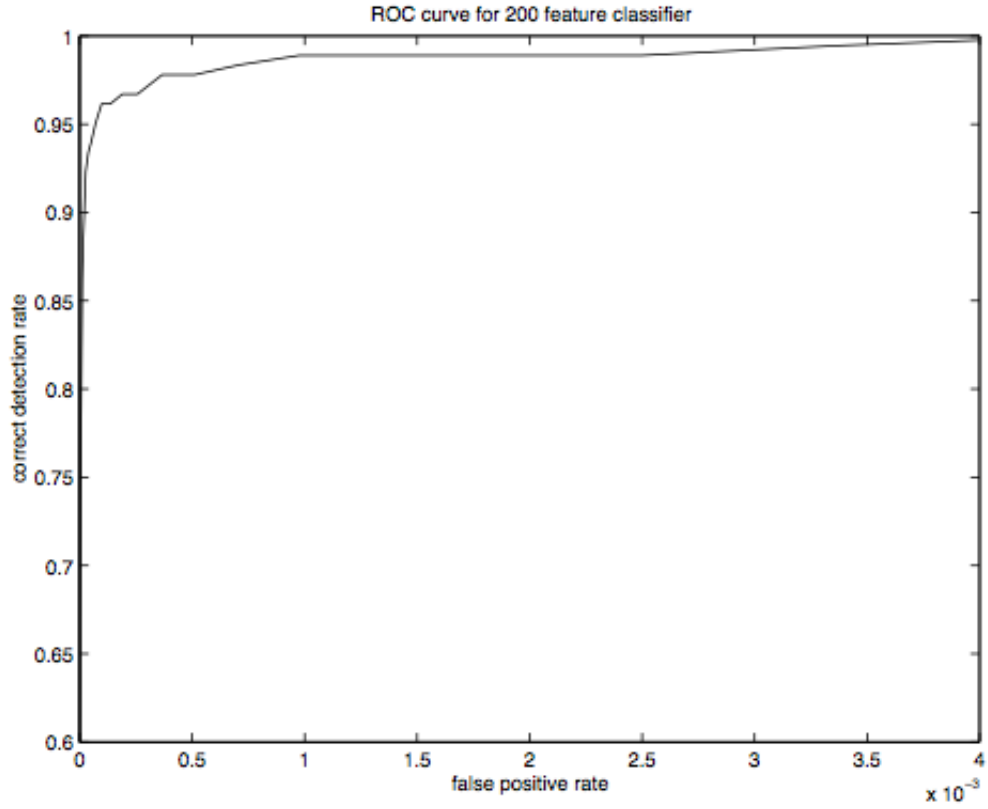


Figure 4.9: Receiver operating characteristic (ROC) curve for the 200 feature classifier

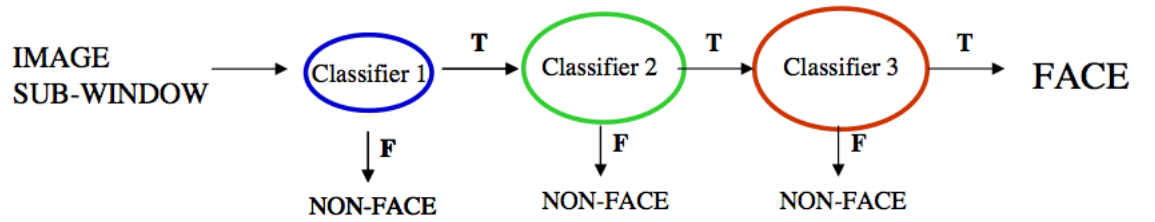


Figure 4.10: Cascade of boosted classifiers

times faster. This is because as soon as the first stage, most negative samples are discarded, so they will not be evaluated ever again afterwards [31].

The cascade method has been made in a way that there must not be false negative

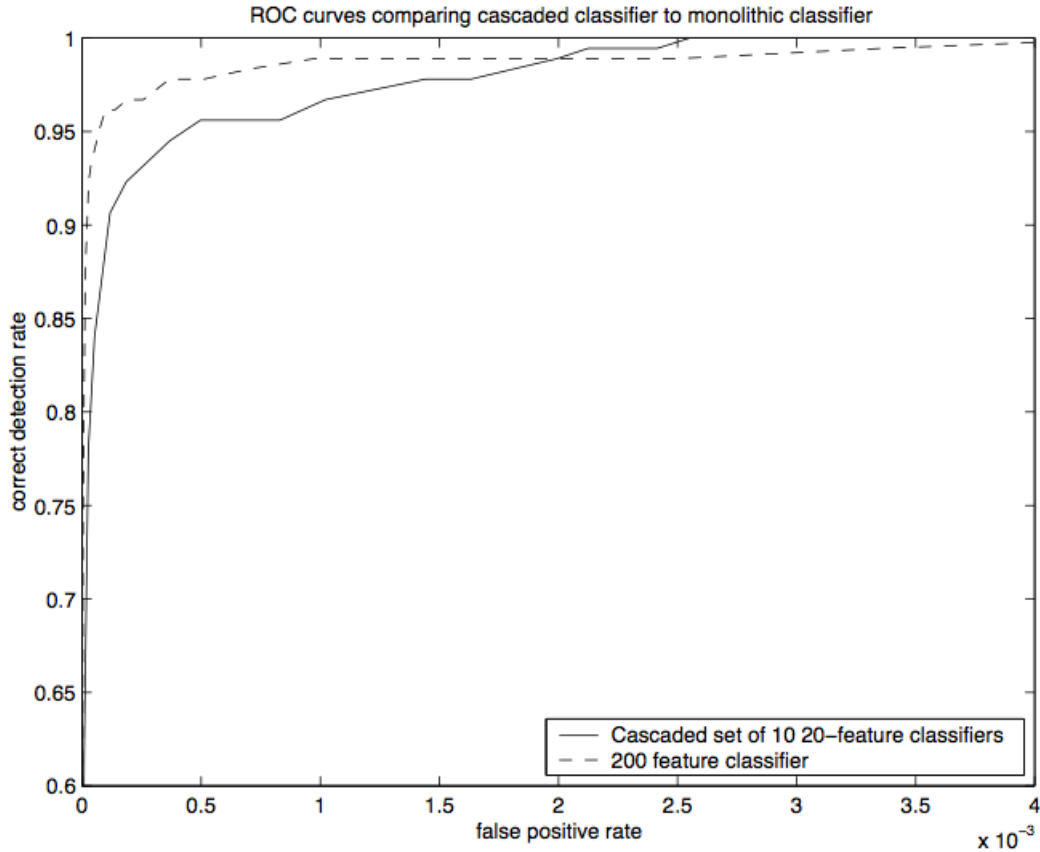


Figure 4.11: ROC curves of a 200-feature classifier and of a classifier cascade containing 10 20-feature classifiers

labeling, meaning that no face should be classified as "Not Face". The assistance threshold has been set low for each level, low enough for the training set to pass all or almost all face examples. All training images that passed previous stages are classified by filters trained to do it for each level. A region is immediately classified as "Not Face" as soon as it failed at one filter. If one of these filters succeeds to pass a region, then it is up to the next filter in the chain. If a region succeed to pass through all the filters present in the chain, then it can be classified as "Face" [11].

The key point of this method is to construct smaller, more efficient, boosted classifiers. They will then detect nearly all positive instances while rejecting a lot of negative sub-regions. Before using complex classifiers to achieve low false positive rates, simple classifiers are called to reject most sub-regions [31].

The order of the filters in the cascade is not random; it is based on the importance weighting assigned by AdaBoost. Heavily weighed are called early, so they eliminate non-face sub-regions as soon as possible. Figure 4.12 shows the first 2 features from Viola-Jones cascade, applied to a face. The first feature used is the one with the eye region being darker than the cheek region. The second feature used is the one with the eyes region being darker than the bridge of the nose [11].



Figure 4.12: The first two Haar features in the original Viola-Jones cascade

The structure of the cascade in itself means that within any single image, most sub-regions are negative. The cascade hence tries to reject as many negatives as possible, starting at the first stage. Indeed, when a positive instance occurs, it will trigger the evaluation of all the classifiers of the cascade, which can be time consuming [31].

Following are the different numbers about cascade classifiers (see Figure 4.13) [19]:

- 1-feature classifier: 100% detection rate and 50% false positive rate
- 5-features classifier: 100% detection rate and 40% false positive rate
- 20-features classifier: 100% detection rate and 10% false positive rate

4.6 Test set and training

The training set is made of about 5000 hand-labelled images of faces. All faces are scaled and have the same resolution of 24×24 pixels. All these faces were chosen

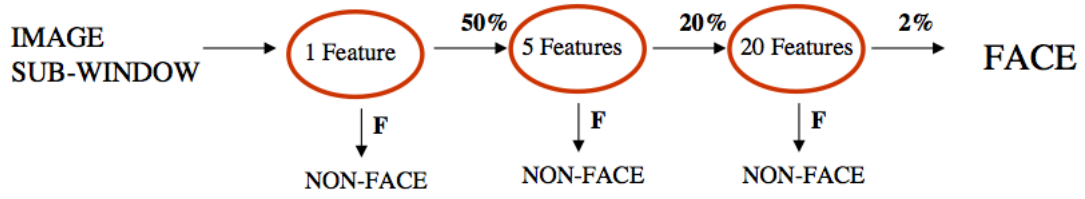


Figure 4.13: Cascade of boosted classifiers positive rate



Figure 4.14: Examples of frontal upright face images used for training

randomly on the internet. Some face examples are shown in figure 4.14 [31].

To sum up, the training set is composed of [19]:

- about 5,000 faces

- All frontal
- 300 million non faces sub-regions
 - from 9,400 non-face images
- Normalized faces
 - Scale, translation
- Many variations
 - Between individuals
 - Lightning
 - Pose (rotation of the head)

There are usually two parts into a test set, first part being training set and second part being validation set. The training set is typically made of about 5,000 positives samples (faces) and 10,000 negative samples (non-faces, usually non-face sub-regions chosen from non-face images) [7]. For this kind of training, and with a 32 layer classifier, the total time usually exceeds several weeks [31].

Viola-Jones training stage proceeds with the following step [7]:

- "Given the number K of possible features (about 160,000 on a 24×24 gray-level image)
- Fix the number L of desired stages in the cascade
- Iterate until L weak classifiers have been selected:
 - Given reweighed data from the previous stage
 - Train all K weak classifiers (find the best threshold to classify the training set)
 - Select the best classifier at this stage
 - Reweight the data"

As said previously, depending on the efficiency of a weak classifier, a weight is associated to it, depending on its classification error rate. Weak classifiers are then linearly combined depending on these weights, this operation having a huge computational cost [7].

Part III

Feature extraction

Contents

This part will focus on the step following face detection, which is feature extraction. Chapter 5 will present the main issues on feature extraction, and usual feature extraction methods, while the following chapter will focus on the Local Binary Patterns algorithm.

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Chapter 5

Feature extraction

After having detected the face, for example using Viola-Jones algorithm, it is necessary to perform feature extraction in order to process data before classification. This step takes an image as input, and extracts vectors characterizing its main features. In the case of a facial expression recognition system, resulting vectors contain informations about spacial configuration of facial features, but can also encode informations about shape, texture or movement of the image's content [5].

There are however many kinds of algorithms outputting features vectors, and the choice of an effective one depends on many criteria. These feature extraction methods can generally be ranked among 2 categories: they can either be appearance-based or feature-based, depending on the way they extract feature vectors. The aim of this chapter is to explain the differences between these 2 types of feature extraction methods, and provide some examples from each category.

Before developing a facial expression recognition project, it is important to know what already exists; the state of the art of facial expression recognition system. In this chapter, an overview will be given of the existing systems before to decide on a feature extraction system for the project.

Two main categories of feature extraction algorithms can be distinguished : *appearance-based* or *geometry-based*. The first ones are algorithms that try to find basic vectors characterizing the whole picture, usually by a dimensionality reduction method. These algorithms lead to a simplification of the dataset, while retaining the main characteristics of the picture. However, these methods have to be carefully parametrized, so they do not encounter the "curse of dimensionality", which is about processing high-dimensional data.

Examples of appearance-based methods : Principal Component Analysis, Linear Discriminant Analysis, Hidden Markov Models, Eigenfaces.

The second type of feature extraction algorithms are geometry-based algorithms. These methods tend to locate important features, and build the feature vectors depending on those regions of interest. The key point of these methods is that the face is not a global structure anymore. Indeed, it has been summarized in a set of

features regions, which are themselves translated into feature vectors.

Examples of geometry-based methods : Gabor Wavelets, Local Binary Patterns.

5.1 Appearance-based methods

As said in the introduction, the Appearance-based method aims to extract the appearance changes of the face. In order to do that the method uses image filters that are applied to the whole face or that are applied to specific parts of the face [25]. With this kind of method, if there is any change in the lightning or the pose of the head, the recognition will be less effective.

5.1.1 Principal Component Analysis (PCA)

This is a statistical method; one of the most used in linear algebra. PCA is mainly used to reduce high dimensionality of data and to obtain the most important information out of it. PCA computes a covariance matrix and a set of values called the eigenvalues and eigenvectors from the original data [9]. Its output is a new coordinate system with lower dimensions, obtained from transformed high dimensionality of data, while preserving the most important information. Since it is a statistical method, it can also be used in the classification step.

5.1.2 Linear Discriminant Analysis (LDA)

Linear Discriminant Analysis is also a statistical method, used to classify a set of objects into groups. It is done by looking at a specific set of features describing the objects. LDA as PCA are used to establish a linear relationship between the dimensions of the data. LDA uses this relationship to model the differences into classes, while PCA does not take any differences into account in the linear relationship. The idea behind LDA is to perform a linear transformation on the data to obtain a lower dimensional set of features [9]. Like PCA, LDA can also be used as a classification algorithm.

5.1.3 Eigenfaces

Eigenfaces are a set of eigenvectors. These eigenvectors are derived from the covariance matrix of a set of images; and this in a high-dimensional vector space. The

eigenvectors are ordered and each one represents the different amount of the variation among images. Characterization of the variation between face images is then possible [27]. Figure 5.1 shows of the first 28 basis vectors of Eigenfaces of the face images.



Figure 5.1: First 28 basis vectors of Eigenfaces of the face images

5.1.4 Hidden Markov Models (HMM)

These models are a set of statistical models used to characterize the statistical properties of a signal [23]. It can be used as a classification algorithm, and can also be developed to recognize expressions based on the "maximum likelihood decision criterion" [15].

5.2 Feature-based methods

As said in the introduction, the Feature-based method aims to locate important facial components. The shape and the location of these facial features are extracted from an face image and then are concatenated into a features vector. This features vector represents the geometry of the face [25].

Compared to Appearance-based method, the Feature-based method has equal or better results. This was recently tested by Valstar et al. [30] [29].

5.2.1 Local Binary Patterns (LBP)

The Local Binary Pattern is a Feature-based method. Its first application was to describe texture and shape of an image by extracting informations from the neighborhood of a central pixel. These informations are the output of the thresholding of intensity values from the neighborhood pixels with the intensity value of the central pixel [9]. One of the advantages of this method is that it is effective even when there is change in lightning (see figure 5.2). This method will be detailed in Chapter 6, and will be used in our facial expression recognition system.

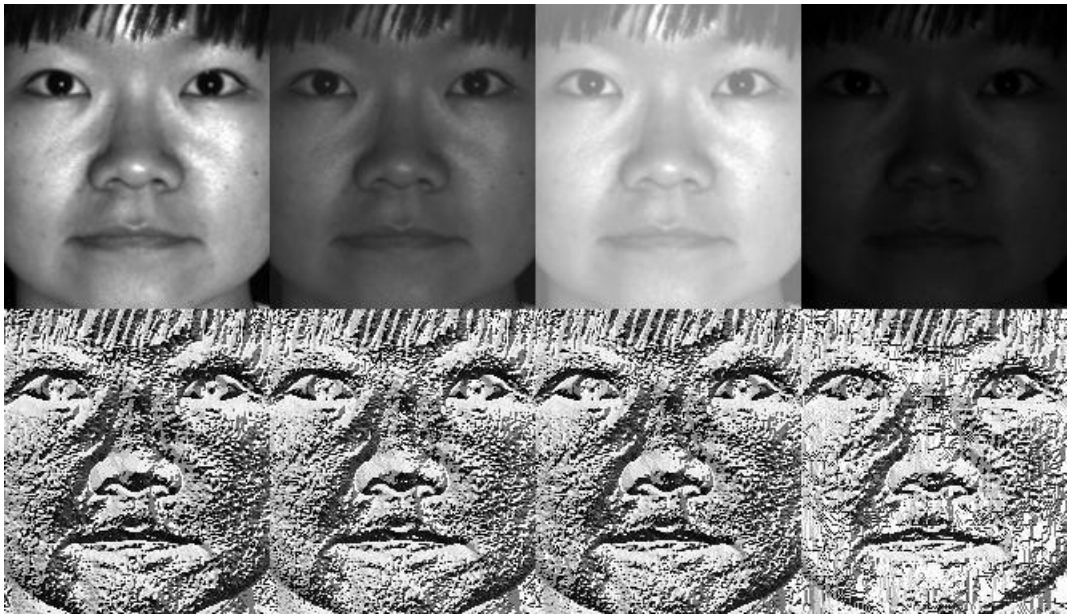


Figure 5.2: Effect of changes in lightning with LBP method

5.2.2 Gabor Wavelets

The most used Feature-based method is the Gabor wavelets because of their performance. Gabor filters are applied in order to extract a set of Gabor wavelet coefficients. Filter responses are obtained when Gabor filters are convolved with face image (see figure 5.3). These representations of face display locality and orientation performance [12]. The disadvantage of this method is that it needs reliable and accurate feature detection and also tracking if necessary [25]. The main limitation of the Gabor feature extraction is processing time. This algorithm is very time-consuming,

and dimensions of resulting vectors are very large [22].

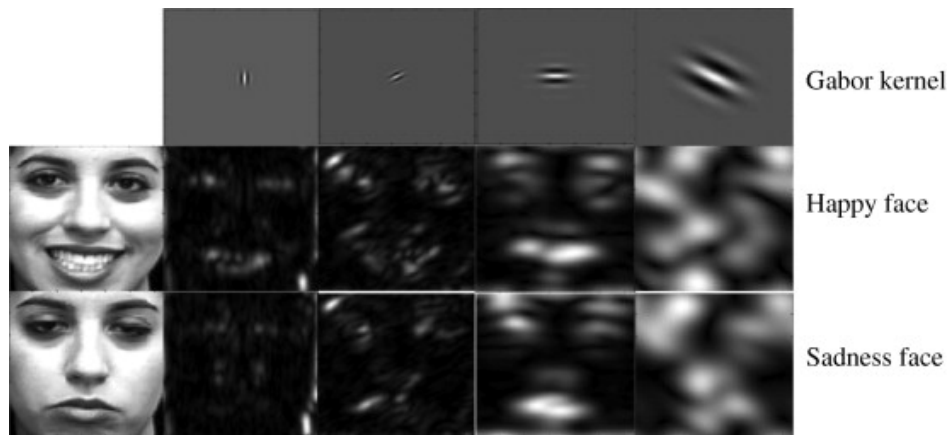


Figure 5.3: Examples of Gabor wavelets and corresponding convoluted images

Conclusion paragraph that opens on LBP

Chapter 6

Local Binary Patterns

Some feature extractions are widely used and studied to characterize and describe the face, such as Principal Component Analysis (PCA) and Linear Discriminant Analysis (LDA). These methods describe the whole image, and are not very efficient if there are changes in lighting or head pose. That is why some researchers turned to local descriptors. These local descriptors describe the face by characterizing parts of the face depending on their importance. The Local Binary Pattern (LBP) feature extraction is a widely used a local descriptor [1].

The LBP operator is known to be an effective texture descriptor because it efficiently describes micro-patterns. Since a face can be seen as a composition of micro-patterns, it is logical to use this texture descriptor. It has been introduced in 1996 by Ojala et al. [20]. This operator has a lot of advantages, one of them being its highly discriminative rate. Other advantages are its invariance to gray-level changes and its computation efficiency, which makes it suitable for image analysis but may not be efficient enough for real-time analysis [1].

6.1 Overview

Globally, a gray-scale image of a face is divided into small regions. LBP histograms are extracted from each of those small regions. These histograms are then concatenated into one feature vector describing the image [13].

The LBP operator works with one central pixel and its eight neighbour pixels. It is a basic binary thresholding between the central pixel and its neighbours. The threshold is set as the intensity value of the central pixel. Then, for each neighbour pixel, if its value is superior or equal to the threshold, a value of 1 is assigned, otherwise a 0. When all neighbours have been processed, a LBP code for the central pixel can be obtained by concatenating all values of its eight neighbours into a binary code. For a better comprehension, a human readable, decimal value can be computed from the binary one. Figure 6.1 shows an example of the LBP process for a pixel and its eight neighbor pixels [13].

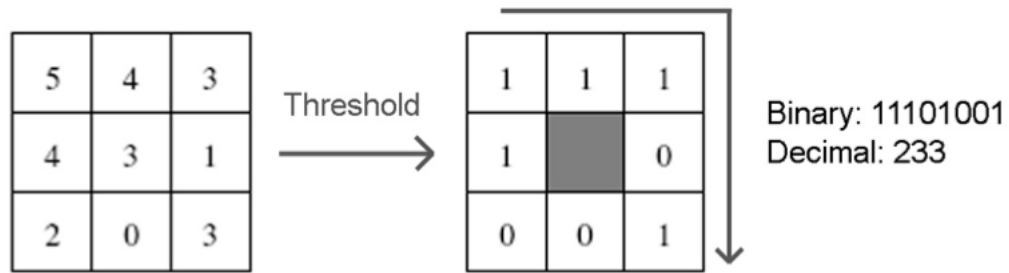


Figure 6.1: Basic LBP operator

Figure 6.2 shows an example of the LBP operator applied on a facial image from the JAFFE database [16].

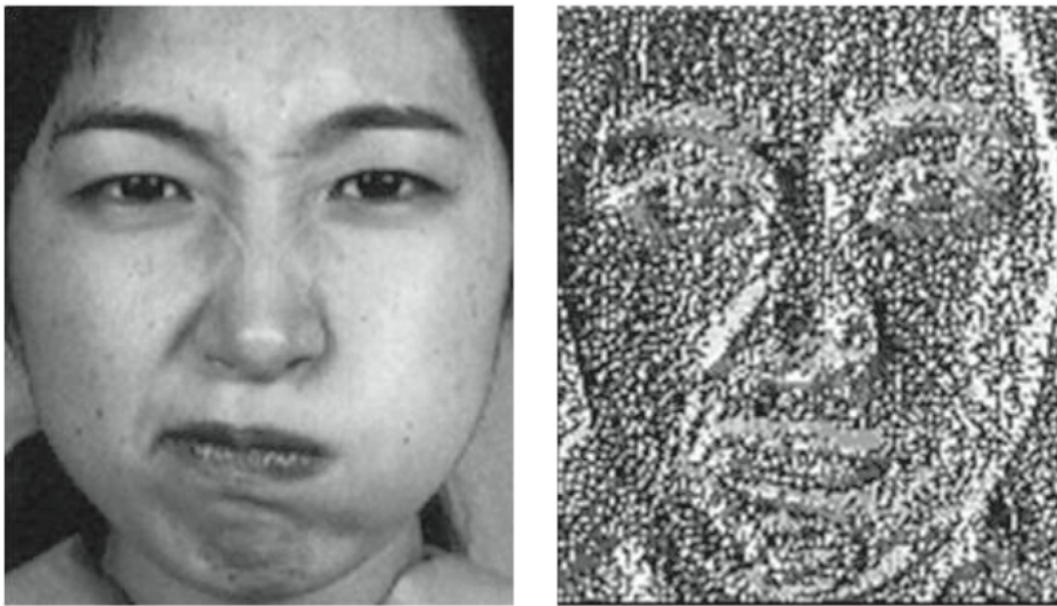


Figure 6.2: Example of the LBP operator applied on a image from the JAFFE database

6.2 Improvements

6.2.1 Circular LBP

In order to be able to use the LBP operator at different scales, a new form of the operator has been introduced. This new form is the circular LBP operator. This way, the operator can be extended to other neighbourhoods than only eight pixels. [9].

This operator still compares the intensity value of the central pixel with its neighbors, but neighbors pixels are now calculated on a circle as follows [9]:

- P represents the number of sampling points (neighbor pixels)
- C represents the central pixel with coordinates (x_c, y_c)
- R represents the distance between each neighbor pixel and the central one

Coordinates of the p^{th} neighbor pixel are calculated with the following formulas [13]:

$$x = x_c + R \cos(2\pi n/P) \quad (6.1)$$

$$y = y_c + R \sin(2\pi n/P) \quad (6.2)$$

Figure 6.3 shows the circular LBP operator with different numbers of neighbor pixels P and with various radius sizes [13]. For the circular LBP operator, the following notation is used: (P, R) and for a pixel p, the following notation is used: $LBP_{P,R}(p)$ [9].

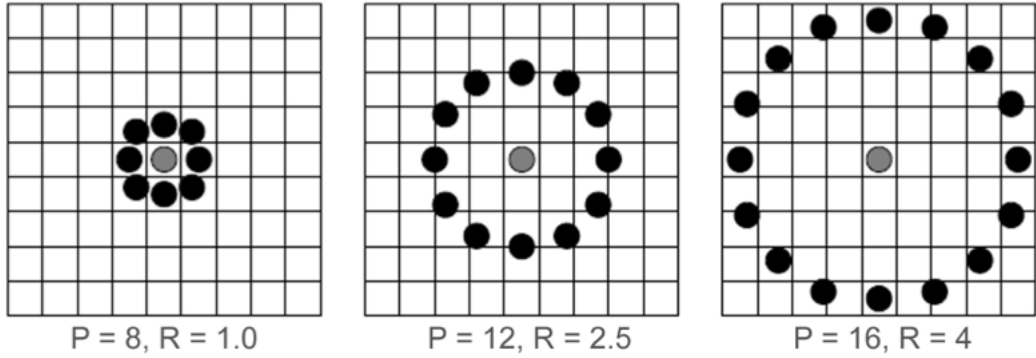


Figure 6.3: Circular LBP operator with different radius sizes R and different number of neighbor pixels P

Most of the time, when a circular LBP operator is used, coordinates of the neighbor pixels (calculated with the formulas given above) may not land exactly on a pixel. In this case, using a bilinear interpolation of neighbor pixels intensity values is recommended. For example, the circular operator with $P = 8$ and $R = 1.0$ is similar to the basic LBP operator; the only difference being during the calculation, if neighbor pixels do not land exactly onto single pixels, these pixels have to be interpolated first [9].

The LBP operation outputs a texture, which formula is [9]:

$$T = t(I_C, I_0, I_1, \dots, I_{P-1}) \quad (6.3)$$

With I_C , the intensity value of central pixel C, I_p for $p = 0, 1, \dots, P-1$, the intensity values of the P neighbor pixels, and T , the texture in the local neighborhood of C [9].

This texture can also be calculated in an other way. The central pixel intensity value can be subtracted from the computed neighbourhood values. Output texture T becomes the combination of differences between intensity values of the neighbor pixels and central pixel, and of the intensity value of the central pixel I_C , resulting in the following formula [9]:

$$T = t(I_C, I_0 - I_C, I_1 - I_C, \dots, I_{P-1} - I_C) \quad (6.4)$$

Based on the work of Ojala et al. [20], $t(I_C)$ describes the overall luminance of an image, which is not related to the local texture of the image. Consequently, relevant information for texture analysis are not provided by this value. It can then be discarded without affecting the texture description [9]:

$$T = t(I_0 - I_C, I_1 - I_C, \dots, I_{P-1} - I_C) \quad (6.5)$$

The above formula makes the texture description invariant against shifts in intensity values. t however does not make it invariant against scaling of intensity values. To obtain a texture description invariant to these scalings, only the signs of the differences are taken into account, and not the difference in itself. The new formula is as follows [9]:

$$T = t(s(I_0 - I_C), s(I_1 - I_C), \dots, s(I_{P-1} - I_C)) \quad (6.6)$$

where,

$$s(x) = \begin{cases} 1 & \text{if } x \geq 0 \\ 0 & \text{if } x < 0 \end{cases} \quad (6.7)$$

For the pixels with an intensity value superior or equal to the one of the central pixel, the sign assigned would be 1. For the pixels with an intensity value inferior to I_C it would be 0 [9].

The last step is to assign a binomial weight to each sign, for the LBP operation. These weights are summed, producing an improved LBP code for central pixel C with coordinates (x_C, y_C) [9]:

$$LBP_{P,R}(x_C, y_C) = \sum_{p=0}^{P-1} s(I_p - I_C) 2^p \quad (6.8)$$

The use of the formula above to calculate LBP still outputs a large number of patterns, which does not help reducing the data size. An other improvement to the LBP operator, called uniform LBP, can then be used to efficiently reduce the data size. This kind of LBP will be explained in the subsection below.

6.2.2 Uniform LBP

A Local Binary Pattern can be called uniform only if it contains 2 or less bitwise transitions. A bitwise transition is a transition from 0 to 1 or from 1 to 0 [9].

In fact, there can be only 2 or 0 bitwise transitions for a uniform LBP. Indeed, the neighbourhood is circular so there cannot be 1-bitwise transition in the pattern. Indeed, if there is a bitwise transition in the neighbourhood, i.e from 1 to 0, it means that there will be another bitwise transition from 0 to 1 further in the circular pattern [9].

If a pattern contains 0 bitwise transitions, it means that it is composed only of 0s or of 1s [9].

For a uniform LBP with a pattern-length of 8 bits (i.e 8 neighbours), containing 2 bitwise transitions, with P neighbor pixels, there are $P(P-1)$ possible combinations. So there are $8(8-1) + 2 = 58$ possible patterns (" +2" is for the 2 patterns with 0

bitwise transitions. The uniform LBP has the following notation:

$$LBP_{P,R}^{u^2}$$

with P numbers of neighbouring pixels and radius size R [9].

There are 2 main advantages coming along with the uniform LBP. The first one is the reduction in range of possible patterns. With the uniform LBP operator, there are 58 possible combinations as seen above, whereas with the basic LBP operator, there are $2^8 = 256$ possible combinations for the same bit-length. The use of uniform LBP then leads to less computation [9].

The second advantage is that, even though there is a reduction of dimensionality, the patterns remain discriminative between various structural features. These structural features detected by the uniform LBP are the spot, the spot/flat, the line end, the edge and the corner, as shown in Figure 6.4 [9].

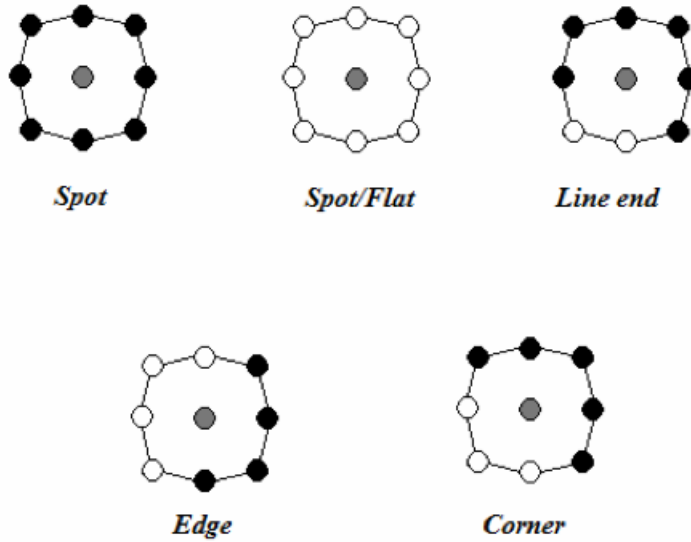


Figure 6.4: Patterns that can be detected with uniform LBP

6.3 Facial Expression Recognition based on LBP

The LBP operator can be used to extract features for a facial expression recognition system. The main idea is to obtain a set of features vectors from the train data,

using LBP. After training the classifiers with these feature vectors, test data will then undergo the same LBP feature extraction before classification.

6.4 Histogram computing

To obtain these features vectors mentioned above, pixel values obtained with the LBP operator are concatenated into an histogram, which will give feature vectors.

To compute this histogram, the face has to be partitioned into regions first. Most of the time, it is partitioned as following: 42 regions, 7 rows and 6 columns. It matches parts of the face yielding important features for emotion recognition. Face dimensions for all tested images should be kept constant. Then for all pixels of the face, their LBP value is computed using $LBP_{8,2}^{u_2}$. Then, resulting values are gathered region-wise into different bins. For example, the LBP operator with $P = 8$ and $R = 1.0$ outputs a histogram with 59 bins: 56 bins for uniform LBP with 2 bitwise transitions, 2 bins for uniform LBP with 0 bitwise transition and the remaining bin for non-uniform patterns). All these bins are concatenated column-wise; as it can be seen in Figure 6.5. The final vector obtained with this histogram is a vector of $42 \times 59 = 2478$ rows, the histogram being computed for each region partitioned on the sample image [9].

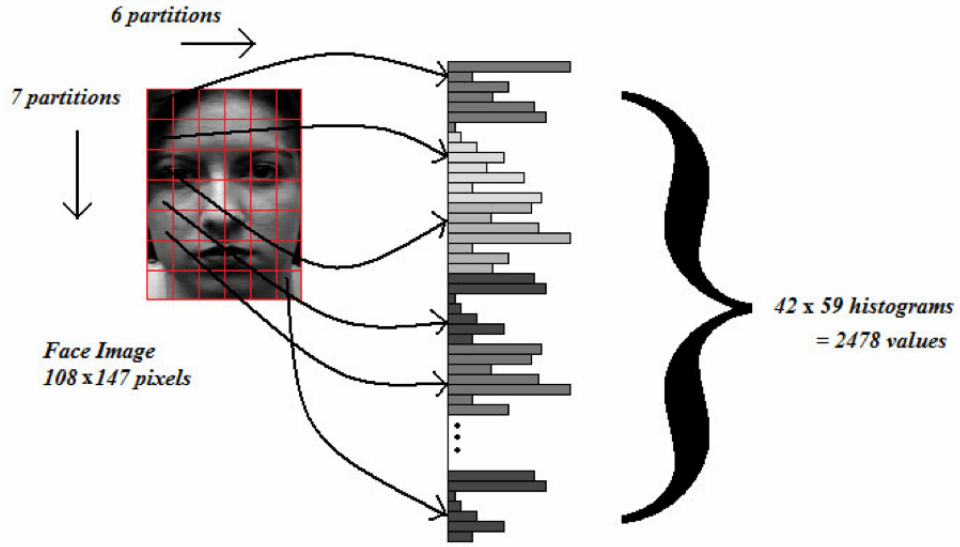


Figure 6.5: Example of a vector based on histogram computing

The regions obtained when the sample image is partitioned do not have the same contribution to the expressed emotion. For example, eyes bring more information about an emotion than cheeks. For each region, a weight is then assigned as in Figure 6.6 [9]. Thus, the histogram of each region is multiplied with a corresponding weight.

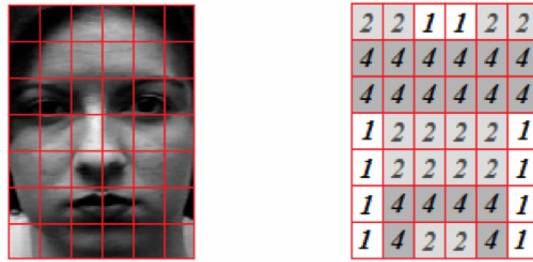


Figure 6.6: Weight assignment for each region

Part IV

Feature classification

Contents

This part will focus on the step following feature extraction, which is feature classification. Classification will be introduced in Chapter 7, with a general overview of the classification problem, along with a presentation of some classification algorithms. The last chapter will describe Support Vector Machine classification.

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8	Support Vector Machine	53
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Chapter 7

Feature classification

bla

7.1 Supervised and unsupervised learning

bla

7.1.1 Supervised learning

bla

7.1.2 Unsupervised learning

bla

Chapter 8

Support Vector Machine

bla

8.1 Overview

bla

8.1.1 Margin maximization

bla

8.1.2 SVM kernels

bla

8.2 Combining LBP and SVM

bla

Part V

Implementation

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blablabla

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Chapter 9

Feature Detection with Viola-Jones

Blablabla

Chapter 10

Feature Extraction with Local Binary Patterns

As said previously, the feature extraction method used for this Facial Expression Recognition system is the Local Binary Patterns method. This chapter describes how this method was used and implemented.

10.1 Uniform Local Binary Patterns

A circular LBP operator, $LBP_{8,1}(p)$, is used with $P = 8$ and $R = 1.0$ to compute the pixel of the face image. The figure 10.1 shows what is obtained with this operator. The operator is also a uniform LBP operator.

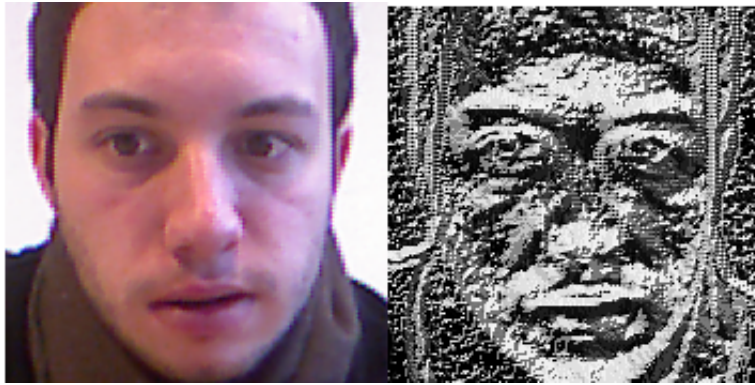


Figure 10.1: Circular LBP operator with $P = 8$ and $R = 1.0$

The face image is divided into regions. As it is commonly done, the face is a grid pattern of 6×7 (6 partitions for the columns and 7 partitions for the rows). In total the face image is divided into 42 regions. For each of these regions, the LBP operator, $LBP_{8,1}^{u^2}$, computes every pixel.

The output of this computation is the number of labelled 1s for the 8 neighbor pixels. Because a uniform LBP operator is used, the number is from 0 to 8. If the number is 9, it means that it is a non-uniform LBP. In total, the output number can have 10 different values (from 0 to 9).

10.2 Histogram computing

The numbers obtained after computing a region are concatenated into an histogram. The histogram has 10 bins; a bin for each value from 0 to 9. Each bin contains the number of pixels that have the value that correspond to that bin. For example, if in a specific region, 20 pixels, after being computed by the LBP operator are labelled with the value 7, then the bin attributed to the value 7 will have a value of 20 for this specific region. The figure 10.2 shows two pixels with their eight neighbor pixels, a region containing these pixels with the values obtained with the LBP operator and an histogram computed for this region.

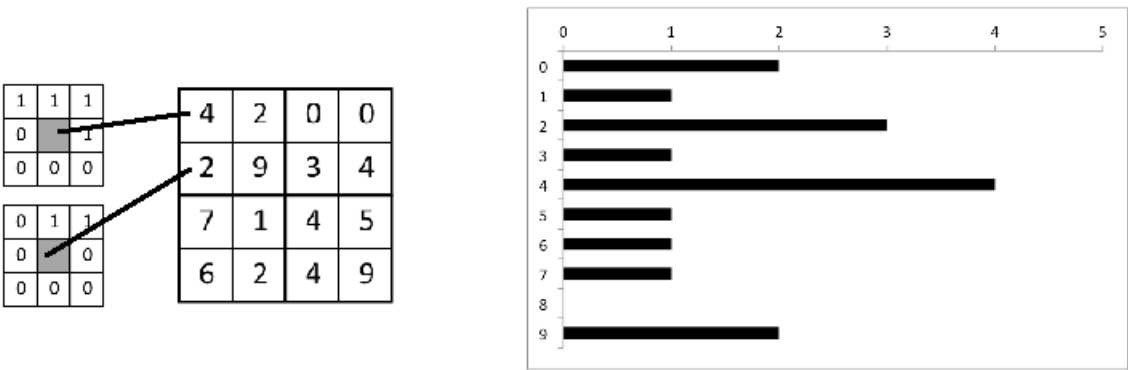


Figure 10.2: Example of Histogram computation

To obtain the feature vector for the whole image, an histogram is computed for each regions. In total, there are 42 histograms computed for the 42 regions. For the whole image, the 42 histograms have in total 420 bins; 10 bins for each histogram. The feature vector is obtained by putting the histogram side to side. The figure 10.3 shows how the feature vector is obtained with all the histograms.

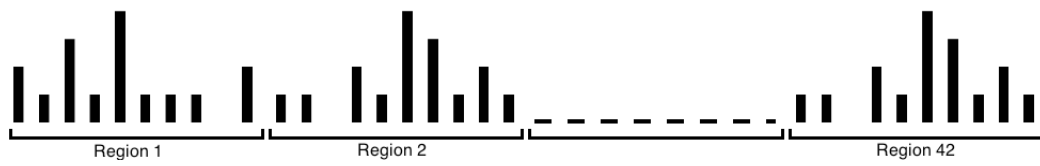


Figure 10.3: Example of a feature vector composed by the 42 histograms

Chapter 11

Feature Classification with Support Vector Machine

blablabla

Chapter 12

Implementation on the Kinect

Blablbala

Part VI

Evaluation

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Chapter 13

Results

bla

13.1 Section name

bla

Chapter 14

Issues

14.1 Feature extraction

bla

14.2 Real-time

bla

Conclusion

In case you have questions, comments, suggestions or have found a bug, please do not hesitate to contact me. You can find my contact details below.

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Appendix A

Appendix A name

Here is the first appendix