Automatic Frontal Face Recognition System Based on Wavelet Decomposition and Support Vector Machines

by

Wang Wei

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Abstract

Automatic Face Recognition (AFR) aims at identifying different human beings according to their face images. Such research has both significant theoretic values and wide potential applications. As a scientific issue, AFR is a typical pattern analysis, understanding and classification problem, related to Pattern Recognition, Computer Vision and Cognitive Psychology etc. Its achievements would contribute to the development of these disciplines.

After more than 30 years' development, AFR has made great progress especially in the past ten years. The state-of-the-art AFR system can perform identification successfully under well-controlled environment. However, a great number of challenges are to be solved before one can implement a robust practical AFR application. The following key issues are especially pivotal: (1) the accurate facial feature location problem; (2) efficient face representation and corresponding classifier with high accuracy; (3) how to improve the robustness of AFR to inevitable mis-alignment of the facial feature. In addition, system design is also as important for developing robust and practical AFR systems. In this thesis, the above-mentioned key issues are studied, aiming at practical automatic frontal face recognition (AFFR) system. And the main contribution of this thesis includes:

1. A novel fast fractal image compression

A novel fast fractal image coding algorithm based on texture feature is proposed. The most fractal image encoding time is spent on determining the approximate D-block from a large D-blocks library by using the global searching method. Clustering the D-blocks library is an effective method to reduce the encoding time. First, all the D-blocks are clustered into several parts based on the new texture feature alpha derived from variation function; second, for each R-block, the approximate D-blocks are searched for in the same part. In the search process, we import control parameter δ, this step avoids losing the most approximate D-block for each R-block. Finally, the R-blocks whose least errors are larger than the threshold given

in advance are coded by the quad tree method. The experimental results show that the proposed algorithm can be over 6 times faster compared to the moment-feature-based fractal image algorithm; in addition, proposed algorithm also improves the quality of the decoded image as well increases the PSNR's average value by 2 dB.

2. Provided a thorough survey of the AFR history

The latest AFR survey was published in the year 2000, which in fact surveyed the AFR researches before 1999. This thesis has provided a more recent overview of the AFR research and development. Then, AFR methods are further categorized according to facial feature extraction, face representation, and classification separately. We also survey the main public face databases and performance evaluations protocols, based on which the state-of-the-arts of AFR are summarized. Finally, the challenges and technical trends in AFR fields are discussed.

3. Proposed an eye location algorithm based on HSV color space and template matching

The quality of feature extraction will directly affect recognition results. Eyes are the one of the most important organs of a face including a lot of useful features. Therefore, eye location has become one of the most significant techniques in pattern recognition.

This thesis proposed an eye location method based on the HSV color space model using template matching. At first, we describe an implementation for skin detection which relies on the H channel to characterize the skin colors range, and determine the possible face region. Then we manually extract an average eye template using the human eye's sample images, and finally in the face region, locate the eyes using this average template. As eye template matching, the rectangular region of the eye which confirmed from the skin region is just searched. Compared to other template matching methods that search for the human eye in whole face region, the proposed method saves on the matching time by avoiding the impact of the mouth and nose in the process of positioning. Undoubtedly, this method enhances the accuracy of eye detection.

4. Investigated the face detection methods, and proposed an improved training AdaBoost algorithm for face detection

Face detection technology as an important part of face recognition has high research and application value. In 2001 the AdaBoost algorithm was applied to face detection by Paul Viola and Michael Jones. The AdaBoost is an algorithm for constructing a strong classifier as linear combine of weak classifier trained by different training sets. The classifiers can be weak (i.e., display a substantial error rate), but their performance is not random (resulting in an error rate of 0.5 for binary classification), they will improve the final model.

In this section, an improved training algorithm for AdaBoost is proposed to bring down the complexity of human face detection. Two methods are adopted to accelerate the training: (1) A method to solve the parameters of a single weaker classifier is proposed, making the training speed is higher than probability method; (2) a double threshold decision for a single weaker classifier is introduced, and the number of weaker classifiers in the AdaBoost system is reduced. Based on the simplified detector, both the training time and the detecting time could be reduced.

5. Primarily studied wavelet transform based feature extraction and Support vector machines to face recognition problem; recognition rate is analyzed and evaluated experimentally

The extracted features from human images by wavelet decomposition are less sensitive to facial expression variation. As a classifier, SVM provides high generation performance without transcendental knowledge. First, we detect the face region using an improved AdaBoost algorithm. Second, we extract the appropriate features of the face by wavelet decomposition, and compose the face feature vectors as input to SVM. Third, we train the SVM model by the face feature vectors, and then use the trained SVM model to classify the human face. In the training process, three different kernel functions are adopted: Radial basis function, Polynomial and Linear kernel function. Finally, we present a face recognition system that can achieve high recognition precision and fast recognition speed in practice. Experimental results indicate that the proposed method can achieve recognition precision of 96.78 percent based on 96 persons in Ren-FEdb database that is higher than other approaches.

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CHAPTER I

INTRODUCTION

1.1 Introduction to Fractal Theory and Its Self-Similarity

In the most generalized terms, a fractal demonstrates a limit. Fractals model complex physical processes and dynamical systems. The underlying principle of fractals is that a simple process that goes through infinitely much iteration becomes a very complex process. Fractals attempt to model the complex process by searching for the sim

ple process underneath. Most fractals operate on the principle of a feedback loop. A simple operation is carried out on a piece of data and then fed back in again. This process is repeated infinitely many times. The limit of the process produced is the fractal.

1.1.1 Fractal Theory

The word "fractal" often has different connotations for laypeople than mathematicians, where the layperson is more likely to be familiar with fractal art than a mathematical conception. The mathematical concept is difficult to formally define even for mathematicians, but key features can be understood with little mathematical background.

The feature of "self-similarity", for instance, is easily understood by analogy to zooming in with a lens or other device that zooms in on digital images to uncover finer, previously invisible, new structure. If this is done on fractals, however, no new detail appears; nothing changes and the same pattern repeats over and over, or for some fractals, nearly the same pattern reappears over and over. Self-similarity itself is not necessarily counter-intuitive (e.g., people have pondered self-similarity informally such as in the infinite regress in parallel mirrors or the homunculus, the little man inside the head of the little man inside the head...). The difference for fractals is that the pattern reproduced must be detailed [MB83, HS12].

Almost all fractals are at least partially self-similar. This means that a part of the fractal is identical to the entire fractal itself except smaller. Fractals can look very complicated. Yet, usually they are very simple processes that produce complicated results. And this property transfers over to Chaos Theory. If something has complicated results, it does not necessarily mean that it had a complicated input. Chaos may have crept in (in something as simple as round-off error for a calculation), producing complicated results. Fractal Dimensions are used to measure the complexity of objects. We now have ways of measuring things that were traditionally meaningless or impossible to measure.

Finally, Fractal research is a fairly new field of interest. Thanks to computers, we can now generate and decode fractals with graphical representations. One of the hot areas of research today seems to be Fractal Image Compression. Many web sites devote themselves to discussions of it. The main disadvantage with Fractal Image Compression and Fractals in general is the computational power needed to encode and at times decode them. As personal computers become faster, we may begin to see mainstream programs that will factually compress images.

A fractal is a mathematical set that has a fractal dimension that usually exceeds its topological dimension[MB04] and may fall between the integers [MB83]. Fractals are typically self-similar patterns, where self-similar means they are "the same from near as from far".[GJ96] Fractals may be exactly the same at every scale, or, as illustrated in Figure 1, they may be nearly the same at different scales [MB83][FK03][BJ92][VT92]. The definition of fractal goes beyond self-similarity per se to exclude trivial self-similarity and include the idea of a detailed pattern repeating itself [MB83][HS12].

1.1.2 Self-Similarity

An object is self-similar only if you can break the object down into an arbitrary number of small pieces, and each of those pieces is a replica of the entire structure. Some examples of self-similarity follow. The red outlining indicates a few of the self-similarities of the object as shown Fig.1.

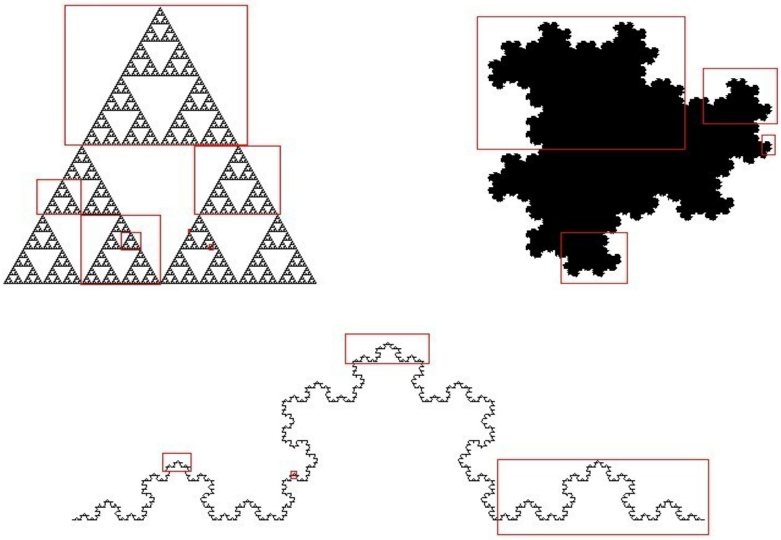


Fig. 1 The Self-Similarities.

Mandelbrot [MB83] offers the following definition of a fractal: A fractal is a set for which the Hausdorff-Besicovitch dimension exceeds its topological dimension. This definition, although correct and precise, is too restrictive, since it excludes many fractals that are useful in physics [FJ89].

An alternative definition is given by Mandelbrot in [MB86]. A fractal is a shape made of parts similar to the whole. This definition uses the concept of self-similarity. A set is called strictly self-similar if it can be broken into arbitrary small pieces, each of which is a small replica of the entire set.

Fig. 2 show the construction of the Koch curve. It begins with a line. In the first step the middle third is replaced by an equilateral triangle and the baseline is removed. This procedure is applied repeatedly to the remaining lines. In the limit there is a strictly self-similar structure. Each fourth of this structure is a rescaled copy of the entire structure.

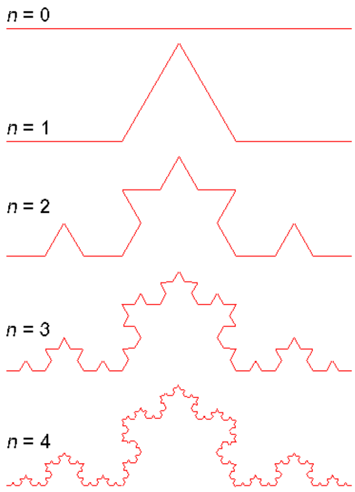


Fig.2 The Koch Curve.

1.2 Fractal Image Compression

Fractal compression is a lossy compression method for digital images, based on fractals. The method is best suited for textures and natural images, relying on the fact that parts of an image often resemble other parts of the same image. Fractal algorithms convert these parts into mathematical data called "fractal codes" which are used to recreate the encoded image.

Fractal image representation can be described mathematically as an iterated function system (IFS).

For Binary Images, we begin with the representation of a binary image, where the image may be thought of as a subset of R^2. An IFS is a set of contraction mappings $f_1, \dots f_N$,

$$f_i: R^2 \to R^2 \tag{1.1}$$

According to these mapping functions, the IFS describe a two-dimensional set S as the fixed point of the Hutchinson operator:

$$\mathrm{H(A)} = \bigcup_{i=1}^{N} f_i\,(A), A \in R^2 \tag{1.2}$$

That is, H is an operator mapping sets to sets, and S is the unique set satisfying $H(S) = S$. The idea is to construct the IFS such that this set S is the input binary image. The set S can be recovered from the IFS by fixed point iteration: for any nonempty compact initial set A_0, the iteration $A_{k+1} = H(A_k)$ converges to S.

The set S is self-similar because $H(S) = S$ implies that S is a union of mapped copies of itself:

$$S = f_1(S) \cup f_2(S) \cdots \cup f_N(S) \tag{1.3}$$

So we see the IFS are a fractal representation of S.

IFS representation can be extended to a grayscale image by considering the image's graph as a subset of R^3. For a grayscale image $u(x,y)$, consider the set $S = \{(x,y,u(x,y))\}$. Then similar to the binary case, S is described by an IFS using a set of contraction mappings $f_1,\ldots,f_N$, but in R^3,

$$f_i: R^3 \rightarrow R^3 \tag{1.4}$$

A challenging problem of ongoing research in fractal image representation is how to choose the $f_1,\ldots,f_N$ such that its fixed point approximates the input image, and how to do this efficiently. A simple approach [FY92] for doing so is the following:

Step 1: Partition the image domain into blocks R_i of size $s \times s$.

Step 2: For each R_i, search the image to find a block D_i of size $2s \times 2s$ that is very similar to R_i.

Step 3: Select the mapping functions such that $H(D_i) = R_i$ for each i.

In the second step, it is important to find a similar block so that the IFS accurately represents the input image, so a sufficient number of candidate blocks for Di need to be considered. On the other hand, a large search considering many blocks is computationally costly. This bottleneck of searching for similar blocks is why fractal encoding is much slower than for example DCT and wavelet based image representations.

1.3 Description of Automatic Face Recognition Problem

Human being seems to have “inherent” face recognition capabilities, to give the computer the same ability is one of the dream of human being, this is called automatic face recognition (hereinafter referred to as AFR). If we take the camera, image scanner, etc. as the computer’s “eyes”, digital images can be seen as a computer “images”, in short, AFR studies have attempted to give computes the ability to recognize people identity according to the facial images they see. Broadly speaking, this recognition ability includes the following different functions:

(1) Face detection and tracking

Face detection tasks require the computer to judge whether there is face in the “images” observer by “eyes”. If there is, we need to give its coordinate position, size information of the face region in the image at the same time. Face tracking needs further output the continuous changes of the detected face position, size, etc. along with time.

(2) Facial feature detection and extraction

This task requires determining the facial image in the eyes, nose, mouth and other organs, also describing the shape information of these organs and their facial contour.

(3) Face classification

According to the result of facial feature detection and extraction, combing with facial image luminance distribution information, judge the gender, facial expression, race, age and other attributes of the detected human face.

(4) Identification based on face image comparison

That is usual sense of the problem of face recognition. This includes two types of recognition: one is close set face recognition, assume that the input face must be an individual in the face database; another one is open set face recognition, first of all, determine whether the input face is in the database, if it is, then identify it.

Development of face recognition allows an organization into three types’ algorithms: frontal, profile, and view tolerant recognition. Frontal recognition is the classical approach. Profile schemes as stand-alone systems have a rather marginal significance for identification. Face recognition can be formulated as: given a static or video image, to identify or verify persons in the scene by comparing with faces stored in the database.

1.4 Face Recognition Research Significance and Typical Applications

Face recognition research began in the late 1960s [CB65, GH71, Ka73, KB76, HH77, HK81], nearly 40 years has been received the considerable development. Especially in recent years, it has become a hot research topic, domestic and abroad well-known universities, research institutions and IT companies get a lot of projects support. Face recognition are taken seriously, because it has important research significance, outstanding performance in two aspects: contribution to the development of discipline and enormous potential applications.

(1) Face recognition can greatly promote the development of many related disciplines.

AFR as a typical image pattern analysis, understanding and classification calculations problem, it provides a good specific issues for pattern recognition, image processing, analysis and understanding, computer vision, artificial intelligence, human-computer interaction, computer graphics, cognitive science, neural computation, physiology, psychology and other disciplines[Ve98, BR02, BT03]. Again, as a computer vision problem, how to integrate the general prior shape information of human faces to accurately restore specific 3D face structure. It is a very valuable research issue [Sh97, GB00, BJ01, Ra02].

(2) Face recognition as a biometric identification technology has great potential application prospect.

Information security, information networks is becoming more and more popular. This brings people more benefits, also brings serious security issues of information acquirement and access. And face recognition as typical biometric identification technology, its natural and high acceptability, etc. can be applied to all walks of life. Table 1 summarizes some typical applications of face recognition.

Table 1 Typical Applications of Face Recognition.

Areas	Specific applications
Entertainment	Video game, virtual reality, training programs
	Human-robot-interaction, human-computer-interaction
Smart cards	Drivers licenses, entitlement programs
	Immigration, national ID, passports, voter registration
	Welfare fraud
Information security	TV parental control, personal device logon, desktop logon
	Application security, database security, file encryption
	Intranet security, internet access, medical records
	Secure trading terminals
Law enforcement and surveillance	Advanced video surveillance, CCTV control
	Portal control, post event analysis
	Shoplifting, suspect tracking and investigation

1.5 Advantages and Disadvantages Using face as Biometric Identification

As mentioned earlier, there are many kinds of biological characteristics identification methods. But their security, reliability and other performance have their merits in terms of authentication. Among them, face recognition is the most important method to identify each other.

1.5.1 The Advantage of Face Recognition Technology

Compared with other biometric identification technology, face recognition technology has unique advantage in terms of usability. Furthermore, face recognition can be completed without any explicit action, participation on the part of the user since face image can be acquired from some distance by camera. Face recognition technical advantages embodied in the following:

(1) It could covert operation, especially for security monitoring

This is applicable to solve important security issues, offender monitoring, cyber pursuit and other applications. This is the fingerprint; iris, retina and other biometric identification technology cannot be compared;

(2) Non-contact acquisition, no intrusive, and easy to be accepted

Therefore, it will not cause physical injury to the user, and conform to the general user's habits;

(3) Convenient, fast and powerful tracking ability

Face-based authentication system could record and save the client's facial while the event occurs, which can ensure the system has good tracking ability.

(4) Low cost image acquisition device

At present, middle and low-grade USB CCD/CMOS camera prices have been low, basically become standard peripherals, greatly expanded the practical space; in addition, digital cameras, photo scanners and other camera equipment, etc. have been more popularity, this further increase its availability;

(5) More in line with recognition habits of human, interactivity is strong

For example, for fingerprints and iris recognition system, the general user to identify is often powerless; but for human face, authorized user interaction and cooperation can greatly improve the system reliability and availability.

1.5.2 Disadvantage of Face Recognition Technology

However, the human face as a biometric identification technology also has its inherent defects, this mainly reflected in:

(1) Poor stability of facial features

Despite the face usually don't change radically (except for intentional cosmetic), but face is strong plasticity of three-dimensional flexible skin surface; it will be changed as the changes of expression and age, etc. The skin characteristics also will be changed with age, makeup and cosmetic, accidental injury;

(2) Low reliability and security

Although different individuals have different faces, overall the human face are similar, and there are so many population on the earth. The different between people face is very subtle, to achieve safe and reliable authentication is quite difficult;

(3) Image acquisition is affected by various external conditions, therefore the recognition performance is low

These disadvantages make face recognition become a very difficult challenge. Especially if the user does not cooperate, the non-ideal conditions, face recognition problem become the current hotter issue. At present, the world best face recognition system only in the ideal situation like user cooperation, the ideal acquisition condition, can basically meet the requirements of general application [PM00, PG03].

1.6 Human visual recognition system characterization

Let the computer has automatic, fast and accurate face recognition ability same as human visual system, it is a dream for researchers. Human visual recognition system naturally becomes AFR frame of reference and bionic foundation. This section simple introduced in literature [CW95, ZCR00] the characteristics of human visual recognition system, looking forward to having referential significance for AFR study.

(1) Is face recognition a specific process? [ZCR00]

Whether the human face recognition mechanism is quite different from other general object recognition? In the human cerebral cortex, is there a dedicated face recognition area? This is one of the focus problems that many researchers have argued for a long time.

However more researchers argue that face recognition system is a special process, it completes this particular object recognition by specialized corresponding cortex. This argument most convincing evidence is “prosopagnosia”. Person suffering from this disease could be normal to identify other objects, even identify nose, eyes, mouth and other facial organs; but cannot recognize familiar faces. So it is reasonable to doubt its face recognition function area was destroyed.

(2) Global features and local features, which is more important?

Global features mainly include human face skin-color feature (such as white, black), the overall profile (such as round face, oval face, square face, long face, etc.), as well as the distribution of facial features. And local features is refers to the characteristics of facial features, for example thick eyebrows, the phoenix eye, crooked nose, mustache beard, pointed chin, etc. and some exotic facial features, such as moles, scars, dimple and so on. A widely accepted view is that: both are necessary for identification, but the global features are generally used to rough matching, the local feature provides more detailed confirmation. But one must be mentioned phenomenon is: if there is a unique local feature (such as scar, mole, etc.), it will first be used to determine the identity. The most important experimental support for global features is called “Thatcher Illusion”, as shown in Fig.3. Where a and b are the inverted images of Thatcher. Although the images are inverted, we can still be easy to determine both are Mrs. Thatcher’s faces, they look very similar. But in fact, their difference is big: in b, its eyes and mouth are inverted. It is relatively seen from c (a inverted) and d (b inverted).

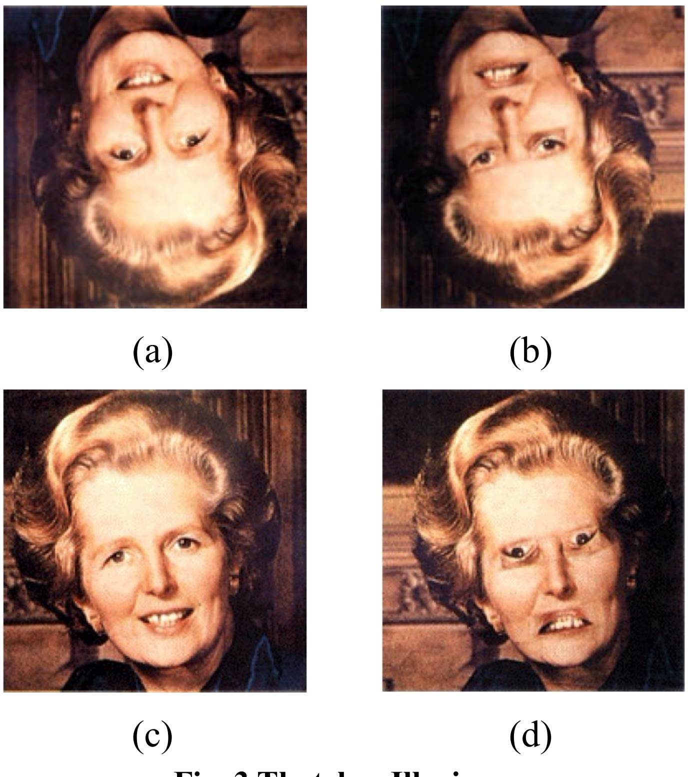


Fig. 3 Thatcher Illusions.

Fig. 4 Example caricatures of some popular stars.

(3) The importance of facial features for recognition [ZCR00]

Different facial areas play different important role on the face recognition. Generally considered, facial contours, eyes, mouth and other features are more important for face recognition. The change of hairstyle for face recognition is also important. But it is worth noting that the hairstyle is available, especially for young people and women. Furthermore, nose in the profile face recognition is more important than other characteristics. That is mainly because in the profile face recognition, nose region contains several key feature points.

(4) Caricatures' enlightenment

We often can see the caricatures.Fig.4 shows caricatures of some popular stars. It is easy to see: caricatures deliberately exaggerated the most important personalized facial features. These features further deepened out understanding of facial characters, making us easier to remember their faces.

In fact this is what the AFR system should extract "unusual" personalized features. The most direct approach is to extract those features which deviate from the average face. AFR method based on Fisherface is trying to extract different features between the different faces for final recognition.

(5) The influence of the gender and age for recognition performance

FRVT2002(Face Recognition Vender Test 2002) test showed that: the identification of women is more difficult than men [PG03]. Generally it is because that woman likes making up. In addition, women aging faster are also the reason. While men seldom make up, and the speed of aging is slow the women. FRVT2002 also showed that the recognition of young people is more difficulty than older adults [PG03]. This is also partly due to young people will be more dress up, changing hairstyles and physiological and psychological change, while the older adults is relatively stable.

(6) Frequency characteristics' relationship with face recognition [ZCR00]

Research shows that: the contribution of different spatial frequency information for identifying is different. For example, to complete the gender recognition, the low frequency information is often enough. And if you want to recognize the subtle difference between different people, the role of the high frequency information is greater. Low frequency information is more apparent overall distribution characteristics of face images; while high information is responding to the local details of change.

(7) Illumination change and face recognition

Illumination change will significantly alter facial appearance, thus influence the performance of face recognition [MA94, AM97]. It has been noticed that the negative face is different to identify. And recent studies showed that: it is also different to identify the below illumination face. This is likely seldom to see such face patterns, and lack of study.

Human visual recognition system more or less provides some guidance for AFR research, even directly affect the AFR's principle and process. But it still needs further research.

1.7 Problem introduction and main contribution of this thesis

1.7.1 Problem introduction

In nearly past decade of research, face recognition technology has made great progress. It has been able to achieve satisfactory result in the case of users cooperate. About 1000 people recognition system the correct recognition rate could be 95%. However this does not mean that the face recognition technology has been very mature. On the contrary, a lot of face recognition systems require to be used on the condition of more extensive face database, camera environment is not controllable and users do not cooperate. The best system under such conditions, the recognition performance decline very quickly. In many cases the identification rate drops to 75%. Clearly the application user cannot accept such performance! Hence, the existing face recognition system has not been mature yet, to develop robust and practical AFR also need to solve a lot of key issues.

Question 1: As a necessary precondition for recognition, the accurate location problem of key facial features

Accurate location of key facial features is the basic premise for a robust and practical face recognition system. A fully automatic face recognition system includes at least face detection, facial feature location, and facial feature extraction and classification steps. Key facial features location is the indispensable part. Meanwhile the key facial feature location directly affects the accuracy of the subsequent feature description and classification. And many AFR research literatures often assumed the key facial features have been accurate positioned, the eye center, canthus and corner of the mouth are calibrated by manual in the experiment. This is actually finished only semi-automatic face recognition. Accordingly, key facial features location is a subject, which has not been enough attention, and must continue to intensive research.

Question 2: Efficient facial feature description and high precision recognition algorithm

The accuracy and robustness of the algorithm is not only depends on what kind of classifier, largely depends on what kind of facial characteristics, which is face representation issue. Theoretically, good face representation can make the most simple classifier has good recognition performance. Human face 3D shape information and the surface reflection properties should be the better face representation. But they are difficult to obtain from the 2D image data, which is not practical. In essence, at present the most mainstream of face recognition is directly using the 2D image as face representation. The disadvantage is affected by the image conditions and various geometric transformations, and it is difficult to obtain high recognition accuracy.

Question 3: How to improve the robustness problem of the AFR system's inevitable registration error

For practical face recognition system, facial feature alignment is indispensable step. Most existing recognition systems rely on facial characteristics (such as eye location) strict registration to normalize the face in order to extract facial descriptive feature. However, the accuracy of facial feature alignment is how to affect the performance of face recognition algorithm? When something goes wrong in the facial feature alignment, how to guarantee the recognition precision will not fall too fast? How to quantitative assess and compare the different algorithms on the robustness of registration error? These key issues have not been gotten sufficient attention.

1.7.2 Main contribution of this thesis

(1) A novel fast fractal image compression

A novel fast fractal image coding algorithm based on texture feature is proposed. First, all the D-blocks are clustered into several parts based on the new texture feature alpha derived from variation function; second, for each R-block, the approximate D-blocks are searched for in the same part. In the search process, we import control parameter δ, this step avoids losing the most approximate D-block for each R-block. Finally, the R-blocks whose least errors are larger than the threshold given in advance are coded by the quad tree method. The experimental results show that the proposed algorithm can be over 6 times faster; in addition, proposed algorithm also improves the quality of the decoded image as well increases the PSNR's average value by 2 dB.

(2) Provided a thorough survey of the AFR history

The latest AFR survey was published in the year 2000, which in fact surveyed the AFR researches before 1999. This thesis has provided a more recent overview of the AFR research and development. Then, AFR methods are further categorized according to facial feature extraction, face representation, and classification separately. We also survey the main public face databases and performance evaluations protocols, based on which the state-of-the-arts of AFR are summarized. Finally, the challenges and technical trends in AFR fields are discussed.

(3) Proposed an eye location algorithm based on HSV color space and template matching

The quality of feature extraction will directly affect recognition results. Eyes are the one of the most important organs of a face including a lot of useful features. Therefore, eye location has become one of the most significant techniques in pattern recognition.

This thesis proposed an eye location method based on the HSV color space model using template matching. At first, we describe an implementation for skin detection which relies on the H channel to characterize the skin colors range, and determine the possible face region. Then we manually extract an average eye template using the human eye's sample images, and finally in the face region, locate the eyes using this average template. As eye template matching, the rectangular region of the eye which confirmed from the skin region is just searched. Compared to other template matching methods that search for the human eye in whole face region, the proposed method saves on the matching time by avoiding the impact of the mouth and nose in the process of positioning. Undoubtedly, this method enhances the accuracy of eye detection.

(4) Investigated the face detection methods, and proposed an improved training AdaBoost algorithm for face detection

In this section, an improved training algorithm for AdaBoost is proposed to bring down the complexity of human face detection. Two methods are adopted to accelerate the training: (1) A method to solve the parameters of a single weaker classifier is proposed, making the training speed is higher than probability method; (2) a double threshold decision for a single weaker classifier is introduced, and the number of weaker classifiers in the AdaBoost system is reduced. Based on the simplified detector, both the training time and the detecting time could be reduced.

(5) Primarily studied wavelet transform based feature extraction and Support vector machines to face recognition problem; recognition rate is analyzed and evaluated experimentally

The extracted features from human images by wavelet decomposition are less sensitive to facial expression variation. As a classifier, SVM provides high generation performance without transcendental knowledge.

First, we detect the face region using an improved AdaBoost algorithm. Second, we extract the appropriate features of the face by wavelet decomposition, and compose the face feature vectors as input to SVM. Third, we train the SVM model by the face feature vectors, and then use the trained SVM model to classify the human face.

In the training process, three different kernel functions are adopted: Radial basis function, Polynomial and Linear kernel function. Finally, we present a face recognition system that can achieve high recognition precision and fast recognition speed in practice. Experimental results indicate that the proposed method can achieve recognition precision of 96.78 percent based on 96 persons in Ren-FEdb database that is higher than other approaches.

1.8 Organization of the Thesis

In the following section, we first review the fractal image compression and propose a novel fast fractal image coding algorithm based on texture feature. We then review and categorize face recognition research in section 3. In section 4, we propose using HSV color space and template matching to locate the eye position; investigates the face detection methods, and propose an improved training AdaBoost algorithm for face detection. Primarily studied wavelet transform based feature extraction and Support vector machines to face recognition problem, presents the automatic face recognition system. The recognition rate is analyzed and evaluated experimentally in section 5. Finally, we conclude our works and discuss the future work.

CHAPTER II

FRACTAL IMAGE COMPRESSION BASED ON TEXTURE FEATURE

The fractal image coding algorithm expresses an image with an iterated function system (IFS) based on image self-similarity. This process regards the natural image as a collection of fractal transformations; it does not code the image content directly. The distortion of decoded image is not caused by the quantitative of mapping parameters; instead, it is produced in the process of generating contractive affine transformations [BW99]. However, it has not been widely used because of its long encoding time and high computational complexity. Fisher has proposed efficient schemes to address the problem. The encoding time is reduced whereas the PSNR is decreased [YF95]. Therefore, the basic contradiction of fractal image coding algorithm is how to maintain a balance between the encoding time and the decoded image quality.

Many fast fractal image coding algorithms have been proposed [HB93,SY04,TY03,SD,CY01,CZ04,WG02,PM98,YC09].Fisher [YF95] proposed the classification method according to the brightness and fluctuations in brightness; Saupe [SD] proposed a method based on the feature vector; Chen Y [CY01] used the definition of range block and domain blocks' characteristic difference to classify; and Polvere [PM98] proposed a method based on the density center; the genetic algorithm was applied to the fractal image coding algorithm[YC09,SK98]; the segmentation scheme has been improved[HW10,MF10,MW10,VR10]. However they only consider some statistic feature of image block, and neglect the image block's content. The fractal image coding algorithm based on texture feature has rarely been studied. The image texture feature has the potential to describe image details.

We propose a novel fast fractal image coding algorithm based on the texture feature derived from the variation function to achieve the high efficiency and high quality. All the D-blocks are clustered to several parts according to the new variation texture feature from small to large. An R-block, firstly determines which part it belongs to, and then it matches only with D-blocks that are in the same part. For each R-block, first calculate in which part it is located. Then judge the absolute value between R-block and the part's boundaries. If this value is smaller than the parameter delta, combine the adjacent parts, and then search in the combined parts. This process could improve the matching accuracy. Tan et al. [TY03] and Chen et al. [CZ04] are both based on the statistical characteristics of the typical coding method, and are representative. The proposed method is based on the texture characteristics. It is comparable to improve its superior to statistical characteristics.

2.1 Architecture of the Proposed Novel Fractal Image Coding System and the Variation Function

The fractal theory was first proposed by B. B. Mandelbrot. In 1981, the Euclidean geometry and the fractal geometry were unified by John Hutchinson, the predecessor of iteration function theory proposed by Barnsley. In 1985, Barnsley formally proposed the iterated function system (IFS); he used it on natural formations, such as clouds, coastlines, and ferns to establish the realistic fractal model; his work was a great success [MF88].

In 1986, Barnsley's team proposed the famous "collage theorem" [MF86] and laid the fractal image coding theoretical foundation. In 1989, Jacquin, Barnsley's PhD student, presented a fully automatic block-based fractal image coding algorithm [AE89]. It constitutes the basic fractal coding schemes, and it has an important impact on the fractal image coding research.

The theoretical basis of fractal image coding algorithm is Iterated Function System (IFS), Banach fixed point theorem and Collage theorem.

2.1.1 Fractal Image Encoding Process

The encoding process is as follows: set f is the encoded gray image. First divide f into B×B (such as B=8, 64 pixels) non-overlapping blocks; these blocks are called range block (R-blocks for short), expressed with R_i.

Then

$$f = \bigcup_{i=1}^{n} R_i \ and\ R_i \cap R_j = \phi, i \neq j \tag{2.1}$$

Second, f is divided into larger overlapping square blocks, called domain block (D-blocks for short), expressed with D_j.

When the division of R-blocks and D-blocks are completed, for a given R_i, we search the most approximate D_j in the D-blocks library, to make the following eq. (2.2) found

$$R_i \approx E_i(D_j) \tag{2.2}$$

Or make eq. (2.3) minimum

$$h_d(R_i, E_i(D_j)) \tag{2.3}$$

Where h_d is the Hausdorff distance, E_i is the basic transformations on the given D_j, j is the subscript of the most approximate matching block.

Here the size of D-block is two times of the R-block, which makes sure that the fixed point can be very similar to the original image. In the matching process, the D-blocks are expanded. For each D-block, first the eight basic transformations are made, such as 0°, 90°, 180°, 270° rotation, vertical midline reflection, horizontal midline reflection, diagonal reflection and so on. These transformations just change the pixels' location; they do not change their gray values. Then the current R-block is compared with the transformed D-blocks. Table 2 shows the eight basic transformations.

Iterated Function System (IFS) is composed by a set of finite affine transformations. We use the following forms of affine transformation:

$$W_i \begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} a_i & b_i & 0 \\ c_i & d_i & 0 \\ 0 & 0 & s_i \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix} + \begin{pmatrix} e_i \\ f_i \\ o_i \end{pmatrix}, i \in 1, 2, \tag{2.4}$$

From (2.4) can be seen that in fact the affine transformation W_i consists of two parts: space transformation $u_i(x,y)$ and gray-scale transformation $v_i(x,y)$. As follows:

$$u_i \begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} a_i & b_i \\ c_i & d_i \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} e_i \\ f_i \end{pmatrix} \tag{2.5}$$

Table 2 Eight Basic Transformations.

Transform type	Transform number	Isometric transformation
Rotation transformation	1	No rotation
	2	Rotation 90 degrees
	3	Rotation 180 degrees
	4	Rotation 270 degrees
Symmetry transformation	5	Vertical midline reflection
	6	Horizontal midline reflection
	7	Diagonal x-y=0 reflection
	8	Diagonal x+y=0 reflection

$$v_i(z) = s_i(z) + o_i \tag{2.6}$$

For an image f, the D_j is mapped to its copy R_i by space transformation $u_i(x,y)$, and the gray-scale transformation $v_i(z)$ determines the gray-scale matching relationship between D_j and R_i.

In (2.4), a_i, b_i, c_i, d_i, e_i, f_i, s_i, o_i are the fractal codes of the given block. After getting all R-block's fractal codes, we get the whole image's fractal codes. In practice, we do not need to find out a_i, b_i, c_i and d_i, only to get the upper left corner coordinates of the most approximate D_j.

Set R_i's pixel gray value is r_k (k=1,2,..., B×B). D_j is mapped into D'j by equation (2.4), the D'j's pixel gray value is d'k (k=1,2,...,B×B). In the matching process, the similarity measure h_d is defined as Eq.(2.7):

$$h_d = \frac{\sum_{k=1}^{N}[r_k - (s_i \cdot d'_k + o_i)]^2}{N}, N = B \times B \tag{2.7}$$

We obtain the upper left corner coordinates of the most approximate D-block which has the smallest h_d value, the corresponding s_i, o_i, and the D-block's basic transformations. These four parameters are current R_i's fractal codes. By obtaining the fractal codes of every R-block, they constitute the whole image's fractal code.

When R-block and D-block are confirmed, s_i and o_i can be calculated using the least square method:

$$s_i = \frac{N(\sum_{k=1}^{N} r_k d'_k) - (\sum_{k=1}^{N} d'_k)(\sum_{k=1}^{N} r_k)}{N\sum_{k=1}^{N} d'_k - (\sum_{k=1}^{N} {d'_k}^2)} \tag{2.8}$$

$$o_i = \frac{1}{N}(\sum_{k=1}^{N} r_k - s_i \sum_{k=1}^{N} d'_k), N = B \times B \tag{2.9}$$

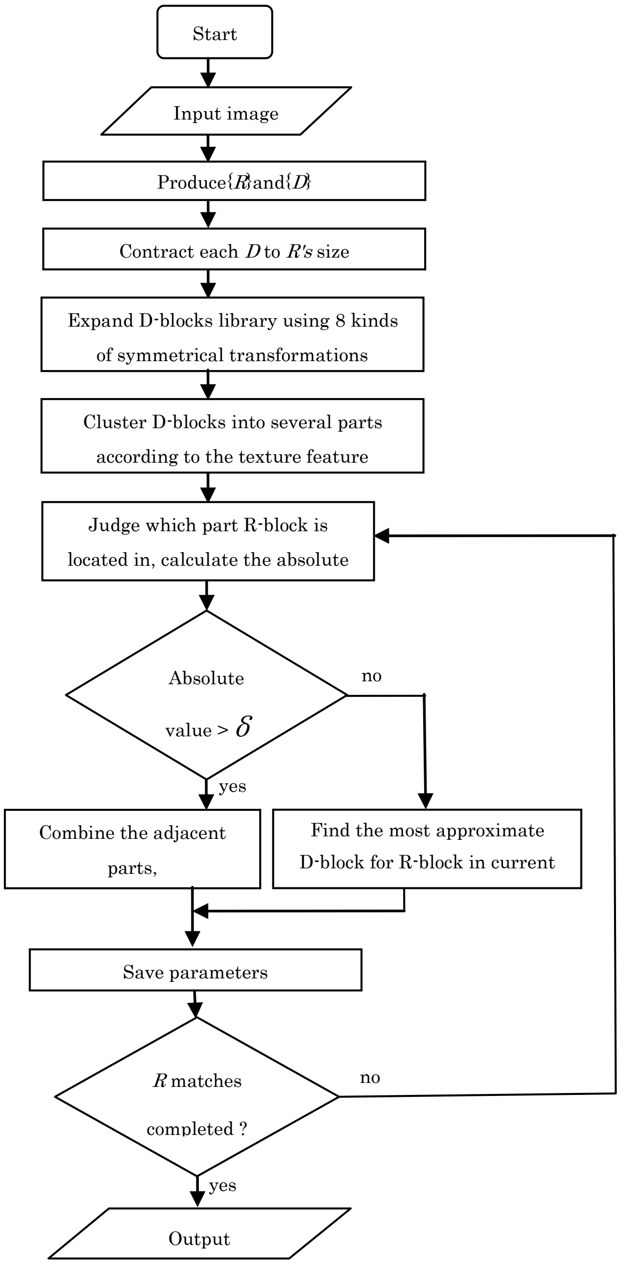


Fig. 5 Flowchart of fractal image encoding.

The s_i and o_i are generally real numbers. To reduce the encoded file's size and improve the compression ratio, it is necessary to quantify s_i and o_i. S_i generally is less than 1. In most study of fractal image coding algorithm, s_i and o_i are respectively quantified with 5 bits and 7 bits.

In this paper, the traditional algorithm was improved. First all D-blocks are clustered into several parts according to image block texture feature. This will greatly shorten the encoding time and improve the coding efficiency. Clustering algorithm has a significant disadvantage is that when the block's eigenvalue is near to the boundary of part, it will make the best matching block lost. Second, in the matching process, after judging which part the current R-block belongs to, the absolute value of R-block's texture feature and parts' boundary is calculated, if this value is smaller than the parameter delta, then combine the adjacent parts, in order to avoid losing the most approximate D-block. The proposed novel fractal image coding architecture is shown in Fig.5.

2.1.2 Fractal Image Decoding Process

Fractal image decoding process is relatively simple; any image can be the initial image. With the stored fractal codes, it can accurately restore the original image after several iterations according to Banach fixed point theorem. There is a certain error between restored image and original image, the Collage theorem controls its upper limit. From a strictly mathematical perspective, this iteration is infinite, but in the actual digital image decoding process, the PSNR tends to be balanced after 6 iterations. It is shown in Fig.6.

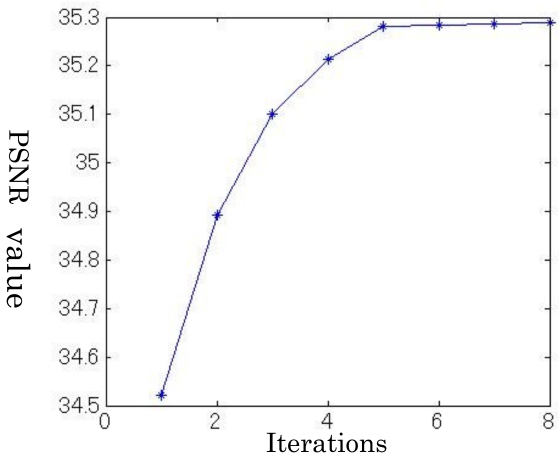


Fig. 6 Comparison PSNR and iterations.

2.1.3 Variation Function

Texture is the special region of image, the pixels in the texture region has some statistical commonalities; certain structures and their repetitions are obvious in vision. But so far the texture doesn't have exact definition and the standard methods of analysis. The variation function theorem [XD10] was established by mathematician G. Matheron in 1962. The variation function considers not only the randomness of regionalized variable but also the spatial structural characteristics of the data. Clearly, the image data is not a purely random variable; it has remarkable structural features, so the image data can be seen as regionalized variables.

The variation function cannot be obtained directly, so the experimental variation function is used in practice:

$$r^*(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i) - Z(x_i + h)]^2 \tag{2.10}$$

Here, h is the distance of two pixel points. $N(h)$ is the number, $Z(x_i)$ is the regionalized variables which has both randomness and structural. Set the pixel gray value $f(x_i, y_i)$, then the values of single variation function are as follows:

$$r_x^*(1) = \frac{1}{2N(1)} \sum_{j=1}^{l} \sum_{i=1}^{l} [f(x_i, y_j) - f(x_i + 1, y_j)]$$

$$r_y^*(1) = \frac{1}{2N(1)} \sum_{j=1}^{l} \sum_{i=1}^{l} [f(x_i, y_j) - f(x_i, y_j + 1)] \tag{2.11}$$

Here, l is the size of image window; $N(1)$ is the number that indicates the distance of two pixel points: it appears as 1 in the window.

Wu et al. [WG02] extracted the feature value of single variation function: r*(1)=r*x(1)cos2θ+r*y(1)sin2θ, where tgθ=α1/α2, α1, α2 are ranges of variation function in the direction of X and Y, and has been proven that it has orientation invariance. Wu et.al [WG02] proposes a novel algorithm for segmentation of texture image based on variation function. Texture feature obtained by the function can characterize random city and structure of texture. The variation value and the variable distance calculated by the variogram function are used for the segmentation of texture image.

Based on the above theory, we propose a new texture feature alpha from the variation function as the clustering standard of the fractal image coding algorithm, and obtain the following lemma and theorem.

Lemma: Given linear bijection F: D→R, then D's alpha equals R's alpha. Where D and R are the domain field and range of F. The feature value alpha is as Eq.(2.12):

$$\alpha = \frac{r_x^*(1)\cos^2\theta + r_y^*(1)\sin^2\theta}{r_x^*(1) + r_y^*(1)} \tag{2.12}$$

Prove: Set F is defined as F(x)=a·x+b, a≠0. Substitute r*x(1) and r*y(1):

$$\frac{r_x^*(1)\cdot\cos^2\theta}{r_x^*(1)+r_y^*(1)} = \frac{\frac{1}{2N(1)}\sum_{i=1}^{l}\sum_{j=1}^{l}[f(x_i,y_j)-f(x_i+1,y_j)]^2\cdot\cos^2\theta}{\frac{1}{2N(1)}\sum_{i=1}^{l}\sum_{j=1}^{l}[f(x_i,y_j)-f(x_i,y_j+1)]^2}$$

$$\frac{\cdot 1}{+\frac{1}{2N(1)}\sum_{i=1}^{l}\sum_{j=1}^{l}[f(x_i,y_j)-f(x_i+1,y_j)]^2}$$

$$= \frac{\sum_{i=1}^{l}\sum_{j=1}^{l}[f(x_i,y_j)-f(x_i+1,y_j)]^2\cdot\cos^2\theta}{\sum_{i=1}^{l}\sum_{j=1}^{l}[f(x_i,y_j)-f(x_i,y_j+1)]^2+\sum_{i=1}^{l}\sum_{j=1}^{l}[f(x_i,y_j)-f(x_i+1,y_j)]^2}$$

Meanwhile,

$$\frac{F(r_x^*(1))\cdot\cos^2\theta}{F(r_x^*(1))+F(r_y^*(1))} = \frac{\sum_{i=1}^{l}\sum_{j=1}^{l}[F(f(x_i,y_j))-F(f(x_i+1,y_j))]^2\cdot\cos^2\theta}{\sum_{i=1}^{l}\sum_{j=1}^{l}[F(f(x_i,y_j))-F(f(x_i,y_j+1))]^2}$$

$$\frac{\cdot 1}{+\sum_{i=1}^{l}\sum_{j=1}^{l}[F(f(x_i,y_j))-F(f(x_i+1,y_j))]^2}$$

$$
=\frac{\sum_{i=1}^{l}\sum_{j=1}^{l}[a\cdot(f(x_i,y_j))+b-a\cdot(f(x_i+1,y_j))-b]^2\cdot\cos^2\theta}{\sum_{i=1}^{l}\sum_{j=1}^{l}[a\cdot(f(x_i,y_j))+b-a\cdot(f(x_i,y_j+1))-b]^2}
$$

$$
\frac{\cdot 1}{+\sum_{i=1}^{l}\sum_{j=1}^{l}[a\cdot(f(x_i,y_j))+b-a\cdot(f(x_i+1,y_j))-b]^2}
$$

$$
=\frac{\sum_{i=1}^{l}\sum_{j=1}^{l}[f(x_i,y_j)-f(x_i+1,y_j)]^2\cdot\cos^2\theta}{\sum_{i=1}^{l}\sum_{j=1}^{l}[f(x_i,y_j)-f(x_i,y_j+1)]^2+\sum_{i=1}^{l}\sum_{j=1}^{l}[f(x_i,y_j)-f(x_i+1,y_j)]^2}
$$

Thus $\frac{r_x^*(1)\cdot\cos^2\theta}{r_x^*(1)+r_y^*(1)}=\frac{F(r_x^*(1))\cdot\cos^2\theta}{F(r_x^*(1))+F(r_y^*(1))}$.

$\frac{r_y^*(1)\cdot\sin^2\theta}{r_x^*(1)+r_y^*(1)}=\frac{F(r_y^*(1))\cdot\sin^2\theta}{F(r_x^*(1))+F(r_y^*(1))}$ can be proved in the same way.

So $\frac{r_x^*(1)\cdot\cos^2\theta+r_y^*(1)\cdot\sin^2\theta}{r_x^*(1)+r_y^*(1)}=F(\frac{r_x^*(1)\cdot\cos^2\theta+r_y^*(1)\cdot\sin^2\theta}{r_x^*(1)+r_y^*(1)})$.

Hence, the lemma is established.

Theorem: IFS based on the affine transformations does not change the image's feature value alpha defined as Eq.(2.12).

We know from the lemma that single affine transformation does not cause the value change of image's feature alpha, that is $\alpha(I)=\alpha(F(I))$.

IFS is composed by a set of finite affine transformations, suppose that :$\{F_1, F_2, \ldots, F_n\}$.

Applying the lemma repeatly, it is easy to get $\alpha(I)=\alpha(F_{i1}\circ, F_{i2}\circ\ldots F_{in}\circ(I))$, where $F_{ik}\in\{F_1,F_2,\ldots,F_n\}$. So the theorem is established.

For each R-block, it compares with the D-blocks that are changed by some affine transformations; however, it does not compare with the D-blocks directly. Therefore, the image blocks and the transformed blocks must be separated in the same part; not all of the image texture characteristics can be considered as clustering standard. They should have the same feature values, or the affine transformation cannot influence the clustering.

The new texture feature alpha is derived from the variation function, and it has been proven that the affine transformation cannot change the value of it; therefore, it can be used in the fractal image coding.

At present, many fast fractal image coding algorithms are proposed to improve the encoding speed, and new schemes appear continually that classifying the image blocks is a very important and effective method. The novel fast fractal image coding algorithm based on the texture feature using clustering method is proposed in this paper.

2.2 Proposed Novel Fast Fractal Image Coding Algorithm Based on Texture Feature

In this paper, we introduce two new modifications into the conventional fractal image coding method. One is using texture information to cluster and find the approximate D-block; another is solving a clustering error.

2.2.1 Clustering Method based on Texture Feature

In the conventional methods, all the D-blocks are clustered into several parts according to their statistic values from small to large. An R-block, firstly determines which part it belongs to, and then it matches only with D-blocks that are in the same part. It will greatly reduce the number of comparisons for each R-block; thereby, the whole encoding time is reduced. In the processing of clustering the image blocks, the standard of the clustering is very important. It does not limit to the image statistic information, such as entropy value or moment feature value. The texture feature can also be used. Few scholars have done research in this area. And the quality of function selected is related to the accurate degree of the cluster.

In this paper a new texture feature alpha is derived from the variation function as the clustering standard. Moreover, its invariance under the affine transformation has been proved. It provides the theoretical basis for being applied to the fractal image coding.

2.2.2 Solving the Clustering Error

There is an obvious disadvantage in the matching process: if the R-block's feature value is very close to boundaries of part which it located in, actually it can be matched only with the unilateral D-blocks. Thereby the set of matched D-blocks is decreased. This may cause the loss of the most approximate D-block, and the matching accuracy is reduced [TY03]. Therefore, this paper has improved this process. The control parameter δ is imported. For each R-block, first calculate which part it is located in. Then judge the absolute value between R-block and (left and right) boundaries. If this value is smaller than the parameter δ, combine the adjacent parts, and then search in the combined parts. By those steps, the matched D-blocks are expanded. These steps avoid losing the most approximate D-block for each R-block.

In summary, to form a novel fast fractal image coding scheme, the process is as follows:

Step 1: Partition the original image f into non-overlapping R-blocks and overlapping D-blocks separately, and then establish D-blocks library;

Step 2: Cluster the D-blocks library to K parts based on the new feature value alpha from small to large, get $\bigcup_{i=0}^{K-1}(Part_i, Part_{i+1}]$, where $Part_i$ is the left or right boundary of parts, and $|Part_{i+1} - Part_i| = L$. The distance L is defined as: $L = \frac{(\max - \min)}{K}$, where K is the clustering number, the max is the maximum value of all the D-blocks' alpha, the min is the minimum value of all the D-blocks' alpha.

Step 3: Calculate current R-block's feature value alpha, and judge which part it belongs to; then calculate the absolute distance between the R-block's value and boundaries. If this absolute distance is less than parameter δ (the definition of δ is 0<δ<0.5L), then combine the adjacent parts, and manipulate the similar matching to find out the D-block that has the minimum error; otherwise, search for the most approximate D-block in the current part which the R-block belongs to;

Step 4: If the minimum error is less than the threshold given in advance, stop matching; otherwise partition the current R-block recursively by the quad tree method to the second matching step, and return to Step 2.

The theoretical analysis and number of experiments have fully demonstrated that this is a new fractal image compression method to improve the efficiency.

2.3 Experimental Results and Discussion

In this section, the seven standard 256×256 gray test images with different complexity are the research objects. The encoding time (s) and the PSNR (dB) of the decoded image are tested, using MATLABR2010a. Experimental hardware environment of the PC is Intel(R) Core(TM) i5 CPU 661; RAM 4.00GB, 32-bit Operating System.

Use the peak signal to noise ration (PSNR) to measure the decoded image quality. The higher the PSNR value, the better the decoded image quality. The original image resolution is M×N×P expressed with f(x,y), and the $\hat{f}(x,y)$ denotes the decoded image. The peak signal to noise ratio (PSNR) is defined as follows:

$$PSNR = 10\log_{10}\frac{b^2}{MSE_{f-\hat{f}}}(dB) \tag{2.13}$$

Where b is the maximum signal value, usually $b=2^p-1$, when p=8, b=255; the MSE is the mean square error, defined as follows:

$$MSE_{f-\hat{f}} = \frac{1}{MN}\sum_{x=1}^{M}\sum_{y=1}^{N}[f(x,y)-\hat{f}(x,y)]^2 \tag{2.14}$$

Compression ratio is the average rate. The original image resolution is M×N×P; N_c in eq. (2.15) is the bytes number of decoded image. In fractal image coding algorithm, we save fractal codes instead of saving image; N_c is the size of code file. Compression ratio Cr is defined as:

$$Cr = (M\times N\times P) / Nc \tag{2.15}$$

Experimental results are as follows:

1) In the experiments, the D-block size is 8×8. The proposed algorithm depends on two control parameters: δ and K.

Actually parameter δ value is proportional to the distance between the parts. In the experiment, parameter δ was taken different values. It achieves the optimal value through the comprehensive analysis of the experimental results. The experimental results show as Fig.3, the encoding time is monotone increasing in $(0,\frac{1}{2})$. The unit of x-axis is the absolute distance of two parts, and the unit of y-axis is second. For an R-blocks, if it belongs to the [$Part_i$, $Part_{i+1}$], we achieve the better encoding time and PSNR values when $\delta = \frac{L}{4}$, K = 20, L is the distance between the Parts. As Fig.7, δ value is $\frac{L}{5}, \frac{L}{4}, \frac{3L}{10}, \frac{2L}{5}, \frac{L}{2}$ respectively.

The clustering number K of the D-block has greatly affected the encoding time; the encoding time changes continuously with the changing of clustering number K (Fig.8). K value is 20, 30, 40, 50, 60, 70, 80, and 90 separately. Obviously the larger the K, the less the R-blocks located on the same part. For an R-block, the D-blocks being matched are less, so that the encoding time is shortened. The encoding time decreases when K increases. In the novel fast fractal image coding algorithm, K=20, $\delta = \frac{L}{4}$.

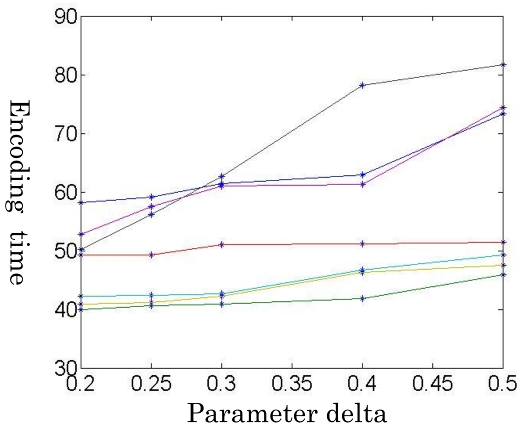


Fig. 7 *δ* vs. encoding time. Using the y-axis points as the criterion, the curves are Lena, Camera, Goldhill, Bird, Peppers, Boat, Barb from top to bottom in turn.

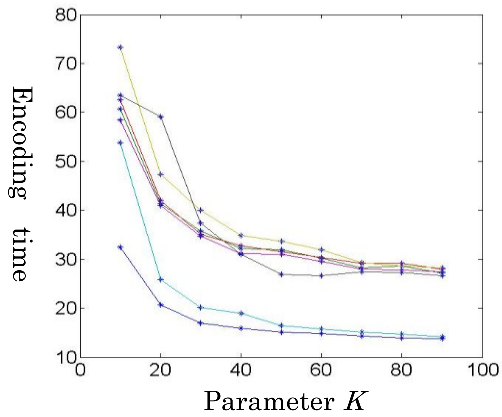


Fig. 8 *K* vs. encoding time. Using the left points as the criterion, the curves are Barb, Bird, Lena, Goldhill, Camera, Boat, and Peppers from top to bottom in turn.

Clustering is a relatively simple and easy method to improve fractal image coding speed. The D-blocks and the R-blocks are divided into the same parts according to their characteristics, and only the similar D-blocks and the similar R-blocks will be matched. This removes the dissimilar blocks, and reduces the numbers of the matching search. The role of clustering is to reduce the search time and change the global search into local search, which achieves the purpose of reducing the encoding time.

1) The PSNR is compared with Tan et al. [TY03], which is based on the images statistical feature entropy. Tan et al. [TY03] analyses the weakness of traditional speed-up techniques for image fractal compression firstly, and proposes a novel idea by using entropy to improve image fractal compress performance. In [TY03] a theorem is proved that the IFS cannot change the image blocks' values. Moreover, it gives a novel fractal compression method based on entropy and its extension. The simulation results illuminate that the new method can improve the PSNR, compress ratio and time cost. But there is an obvious disadvantage mentioned. The introduction of control parameter δ is intended to settle this matter; these processes improve the quality of the decoded image(as Fig.9). We can see that the average PSNR value is improved; the average PSNR value of the Tan et al. [TY03] is about 32.96 dB. The average encoding time is 41.56 seconds.

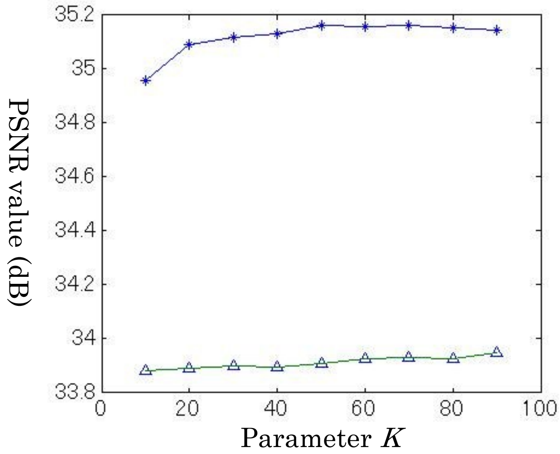


Fig. 9 PSNR Comparison with Tan et al. [TY03]. The star curve represents the novel fast fractal image coding algorithm, and the triangle curve represents the Tan et al. [TY03] respectively.

3) The decoding process is shown as Fig.6. In the graph, the decoded image has been recovered into the original image when the iteration is 6 times and the clustering number K is 20. Fig.10 is the decoding process about the proposed algorithm.

4) Additional experiments were carried out. Fig.7 is the comparison result between the proposed algorithm and Chen et al. [CZ04] based on moment

One iteration Two iterations Three iterations

Four iterations Five iterations Six iterations

Fig. 10 Decoded image with D-block size of 8×8.

invariant. In Chen et al. [CZ04], all the domain blocks are clustered into several categories, and search for its best-match domain block in those with the same category or adjacent categories, hence reducing dramatically the number of domain blocks needed to be compared with. With the increasing of clustering number K, the encoding times is reduced; however, the novel fast fractal image coding algorithm can be 6 times quicker compared to the studies cited in the Chen et al. [CZ04]). The average time of the proposed method is about 40.798 seconds, and the average time of Chen et al. [CZ04] is about 276.988 seconds.

The encoding time is also reduced with the increasing of clustering number K based on the moment invariant; however, the computational complexity of the moment invariant is too large [CZ04]. In the novel fast fractal image coding algorithm, we use the new texture feature alpha as the clustering standard whose calculation is less than the moment invariant; this process could reduce the computation. The result shows that the encoding time is significantly faster (nearly 6 times), so the new texture feature is better than the moment invariant. This new clustering feature alpha does not only have less computation; it also can describe the image texture feature. The average PSNR value is about 35.10 dB. It is higher than the PSNR cited in the Chen et al. [CZ04]; the average PSNR value cited in the Chen et al. [CZ04] is 33.93 dB. Fig.11 is the decoded image of Chen et al. [CZ04] after 6 iterations. Fig.12 shows the rate-distortion curve between proposed algorithms and Tan et al. [TY03] based on the entropy feature. The average compression ration of the proposed method is 14.15, and Tan et al. [TY03] is 14.63.

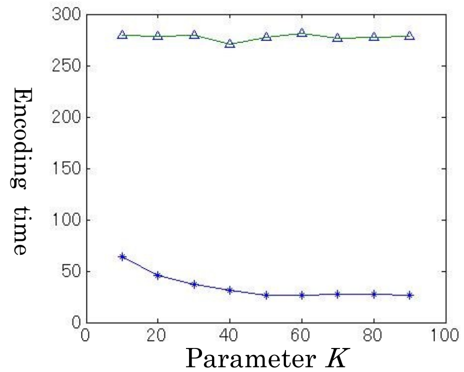


Fig. 11 Encoding time Comparison with Chen et al. [CZ04]. The star curve represents the novel fast fractal image coding algorithm, and the triangle curve represents the Chen et al. [CZ04] respectively.

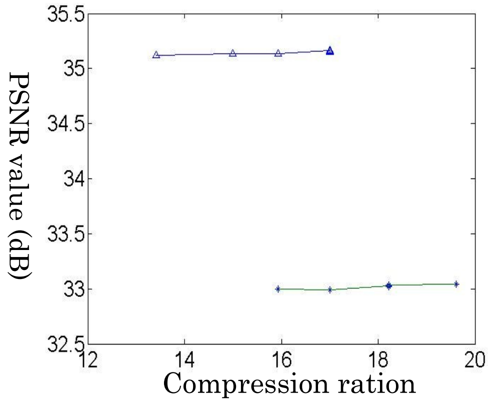


Fig. 12 Rate-distortion curve. The triangle curve represents the novel fast fractal image coding algorithm, and the star curve represents the Tan et al. [TY03] respectively.

Table 3 contains the experimental results of different test images regarding their PSNR values. The results show that the qualities of the decoded images have been increased compared with Tan et al. [TY03].

In this paper a novel fast fractal image coding algorithm based on the image texture feature alpha has been proposed. We cluster the D-blocks according to the new texture feature alpha based on variation function to reduce the encoding time. The introduction of the control parameter δ is to avoid the loss of the most approximate D-block. The simulation results show the timeliness and effectiveness of the proposed algorithm; it can quicken the process by over 6 times. Decoded image quality is also improved. Fig.13 shows the decoded image of different test images.

Table 3 PSNR results comparison with different text images.

Images	Proposed algorithm	Tan et al. (6)
Lena	35.10	32.96
Barb	32.02	32.98
Bird	35.95	34.44
Camera	30.86	28.89
Goldhill	31.18	33.75
Boat	30.75	33.08
Peppers	34.19	33.96

Fig. 13 The results for the Peppers, Gledhill, Bird, Boat, Camera and Barb with D-block size of 8×8.

CHAPTER III

REVIEWS OF FACE RECOGNITION RESEARCH

The latest review articles of face recognition research are published in 2000. Considering the lag period of the published journal articles, the content is all overview before 1999. This chapter will include the latest research results in recent year. In addition, we also summarized the existing main commercial face recognition systems, and summarized their characteristics and technical basis.

3.1 General Computational Model of Face Recognition

Usually the face recognition what we call is based on the optical identification and verification. Optical face image (hereinafter referred to as face image) is the light intensity that the external light source illuminates on the human face after face surface reflection. It is easy to understand, this imaging process actually involves three key elements:

(1) Face internal attributes

Including facial surface reflection properties, 3D face shape, and facial expression, beard and other property change;

(2) External imaging condition

Including light source, other objects, or other body parts shade the face;

(3) Camera imaging parameters

Include the camera position, the camera focal length, aperture, shutter speed, and other parameters.

Therefore, the forming process of optical image can be simply formalized as follows:

$$I = f\,(F;L;C) \tag{3.1}$$

Where, f express image function, F, L and C represent the face internal attributes, external image conditions and camera imaging parameters. I is generated face image. Assume that: facial skin reflection properties meets Lambertial model, face is convex surface structure, light source is infinity monochromatic point light, and the equation can rewritten as:

$$I(x,y) = f_c(\rho_{(x,y,z)}\vec{n}_{(x,y,z)} \cdot \vec{s}_{(x,y,z)}) \tag{3.2}$$

Where, (x,y,z) is face point P's three-dimensional coordinates, $\rho_{(x,y,z)}$ represents point P's surface reflectance, $\vec{n}_{(x,y,z)}$ is point P's surface normal vector, $\vec{s}_{(x,y,z)}$ is light source direction and intensity, f_c indicates camera imaging function, $I(x,y)$ is camera final output corresponding to point P.

Set input image is I, this process can be formalized as the following three steps:

(1) Properties separation. Separate facial essential attribute and light condition s*, camera parameters c*:

$$\left(\rho^*_{(x,y,z)}, \vec{n}^*_{(x,y,z)}, s^*, c^*\right) = f_c^{-1}\left(I(x,y)\right) \tag{3.3}$$

(2) Feature extraction. Extract the features which could reflect certain facial identity from the face attribute elements:

$$F^* = T\left(\rho^*_{(x,y,z)}, \vec{n}^*_{(x,y,z)}\right) \tag{3.4}$$

Where T says feature extraction process.

(3) Classification discriminant. Compare the extracted features with stored feature in the database; select the most similarity as identity information:

$$ID^* = \underset{i \in \Omega}{\arg max}\left(Sim(F^*, F_i)\right) \tag{3.5}$$

Where $Sim(.)$ is similarity between computing features, Ω is known face set.

It should be pointed out that in recent years, Blanz and Vetter proposed 3D deformable model approach [BV99, BR02, BT03] is an important theoretical model above theoretical. It has attracted researchers' attention; although there are still many problems, such as speed and recovery accuracy, we believe there will be greater breakthrough in this area.

3.2 Research History and Present Research Situation

Face recognition has a relatively long history. Galton published two articles in《Nature》 magazine as early as 1888 and 1910 respectively. It analyzed the human being's face recognition ability, but it was impossible to involve the automatic face recognition problem. The earliest AFR research paper is technical report by Chan and Bledsoe in Panoramic Research Inc. [CB65], it has more than 30 years history. In recent year, face recognition has been favored by many researchers. Especially since 1990, face recognition has gotten rapid progress. Now, almost all well-known IT industry and science engineering university have research groups engaged in face recognition research. 1999 years ago, face recognition research can be found in the following several review articles:

[SI92] Samal &Iyengar, "Automatic Recognition and Analysis of Human Faces and Facial Expressions," Pattern Recognition, vol.25, 1992

[VA94] Valentin, Abdi, O'Toole & Cottrell, "Connectionist Models of Face Processing: A Survey," Pattern Recognition, vol.27,1994

[CW95] Chellappa, Wilson & Sieohey, "Human and Machine Recognition of Faces: A Survey,"Proc.IEEE,vol.83, 1995

[Gr00] Grudin, "In Internal Representations in Face Recognition Systems, "Pattern Recogniton, vol.33,2000

[ZCR00] Zhao, Chellappa,Rosenfeld & Phillips, "Face recognition: A Literature Survey," UMD CS-TR-4167, 2000

It should be noted that the face recognition is a widely studied hot problem, a large number of research papers are emerging in an endless stream, to a certain extent, and it has flooded into a "disaster". In order to introduce the face recognition history and current status better, this article will divide the AFR history into three stages in accordance with research content, technical methods. As shown in Table 4, this table summarized the brief history of the development of face recognition and its research and technical characteristics of each historical stage. The following simple introduced the research progress of three phases:

The first phase (1964~1990)

This phase the face recognition was usually studied as general pattern recognition problem. The principal technical solution was based on facial geometric structure feature [CB65,GH71,Ka73]. This focused on profile research. Artificial neural network also had been used in face recognition problem. Earlier researchers engaged in AFR besides Bledsoe and Goldstein [GH71], Harmon [HH77, Hk81] and Kanade [Ka73]. Dr Kanade at Kyoto University in 1973 completed the first AFR PhD dissertation [Ka73]. Until now, as the Carnegie Mellon University professor, Dr. Kanade is still active in the field of face recognition. His research group is also an important force [RB98,GM02]. In general, this phase is the initial stage of face recognition research, not many important results, basically did not get practical application.

The second phase (1991~1997)

At this phase, in despite of the relatively short time, but it was the height of face recognition research and it was a productive and fertile period. Not only generated number of representative face recognition algorithm, the US military has also organized the famous FERET face recognition algorithm testing [PM00]. And a number of commercial face recognition systems were appeared, such as the most famous example Visionics (now Identix) FaceIt system [PA96].

Table 4 A Brief History of Face Recognition Research.

Development stage	**1964~1990**	**1991~1997**	**1998~Current**
Main feature	Studied as general problem; feature-based approach is the mainstream	Focused on solving the more ideal conditions, small and medium database for face recognition problem; Appearance-based 2D face image analysis and statistical pattern is the mainstream	Focused on solving the non-ideal conditions, large database; based on 3D models and nonlinear modeling method may be the development trend
Typical face recognition	The earliest known AFR research papers [CB65]	Eigenface [TP91]	Illumination cone method [GK98, GB01]

<table>
<tr><td rowspan="8">technology and key events and works</td><td rowspan="2">The first semi-automatic face recognition system [Ka73]</td><td>Feature-based and template-based methods comparison [BP93]</td><td>Support Vector maching used for face recognition [Ph98, GL00,JM00,DC01,JK02]</td></tr>
<tr><td>American DARPA launched FERET test project [PM00]</td><td>3D deformable model [BV99, RB02,BR02,BT03]</td></tr>
<tr><td>The first AFR doctoral dissertation [Ka73]</td><td>Local feature analysis(LFA) face recognition become Visionics company Facelt business systems [PA96]</td><td>Face detection based on AdaBoost [VJ01, VJo01]</td></tr>
<tr><td>Silhouette-based analysis(profile) face recognition [KB76, HH77,HK81]</td><td>Gemini space-based Bayesian probability learning [MP97]
Face recognition research summary [CW1995]</td><td>ISOMAP [TS00] and LLE [RL00]
Lambertian reflection and linear subspace analysis [BJ01,BH01,LH01,Ra02]</td></tr>
<tr><td rowspan="4">A low-dimensional representation of face [SK87, KS90]</td><td>Fisherface [BH96, BH97]</td><td>Face recognition based on quotient image[SR01]</td></tr>
<tr><td>Elastic graph matching techniques [BL90, LV93,WF97]</td><td>Face detection summary [YK02]</td></tr>
<tr><td>ASM/AAM [LT94, LT95,LT97,CE98,EC99]</td><td rowspan="2">Face recognition vendor test 2000, FRVT 2002 test [PG03]</td></tr>
<tr><td>FERET’1996 test [PM00]</td></tr>
<tr><td rowspan="5">Technical features</td><td colspan="2">Feature-based approach</td><td>Template-based approach</td></tr>
<tr><td>…</td><td>Recognition method based on neural network</td><td>…</td></tr>
<tr><td colspan="2">…</td><td>Statistical learning theory</td></tr>
<tr><td colspan="2">…</td><td>Appearance-based 2D face image analysis and statistical pattern</td></tr>
<tr><td colspan="2">…</td><td>The nonlinear analysis</td></tr>
</table>

		techniques
	Face recognition based on 2D image model	Based on 3D image model

MIT Media Lab Turk and PEntland's "Eigenface" [TP91, PM94] is undoubtedly the most prestigious recognition method this period. Subsequent face recognition techniques are more or less have relationship with Eigenface [BH97, MP97, MP00, ZC98, Liu99]. Now Eigenface and normalized correlation method [BP93] is the performance test benchmark algorithm of face recognition.

In general, this phase the human face recognition technology was developing very rapidly. The proposed algorithm achieved good performance in the ideal condition, user coordinate, the small medium database. Thus there have been appeared several well-known face recognition commercial companies. From the point of view of the technical, 2D face image subspace statistical pattern recognition method is the mainstream technology.

The third phase (1998~now)

FERET'96 face recognition algorithm evaluation showed that: main face recognition technology' robustness is poor in the condition of non-ideal acquisition conditions or the user does not cooperate [PM00]. To this end, the U.S military based on the FERET test respectively organized two commercial systems evaluation in 2000 and 2002 [PG03].

Georghiades et proposed the face recognition method based on illumination model which was one of the important achievements of this period [GK98, GB01]. In order to compute the illumination cone from the small unknown lighting conditions, they also extended the traditional photometric stereo vision method.

Support vector machines as the representative of statistical learning theory has been applies to the face recognition [Ph98, GL00, JM00].

Blanz and Vetter proposed the face image analysis and recognition method based on 3D Morohable model, which is the groundbreaking work [BV99, RB02, BR02, BT03]. This method is essentially a synthetic-based analysis. Its main contribution is based on the 3D shape and texture statistical deformation model; it also uses graphics simulation method for image acquisition and illumination model parameters.

At the 2001 international conference on computer vision (ICCV), Compaq institute researcher Viola and Jones presented their real-time face detection system based on simple rectangle features and AdaBoost. In CIF format, the frontal face detection r ate reached more than 15 frames per second [VJ01, VJo01].

Shashua et al proposed face image recognition and rendering technology bases on quotient image [SR01]. This technical is based on a specific object class drawing technology.

Basri and Jacobs proved an important conclusion; using Spherical Harmonics represents light, and using convolution process description Lambertain reflection: Lambertain collection obtained by arbitrary far point source forms a linear subspace [BJ01]. This is not only the light of previous experience statistical modeling experimental results. Further theoretical linear subspace promotes the development of object recognition method [BH01, LH01, Ra02].

After FERET project, a number of commercial face recognition systems have sprung up, U.S department of defense organized further evaluation for commercial face recognition systems—Face Recognition Vendor Test(FRVT), until now has been held twice: FRVT2000 and FRVT2002 [PG03]. These two tests, on the one hand, compared well-known face recognition systems' performance.

In general, the non-ideal image conditions (especially the illumination and posture), user does not cooperate, large face database on the face recognition problems gradually become research hotspot. The nonlinear model method, statistical learning theory, learning method based on AdaBoost, 3D model face and identification methods have been become highly regarded technology trends.

3.3 Main Technical Classification of Face Recognition

A practical AFR system includes at least face detection, facial feature point's automatic calibration, facial feature extraction and classification. For a pattern recognition system, what kind of features is used to represent the model, how to extract the features often are the key issues. Therefore this section presents the corresponding reference and brief description in tabular form. Table 5 shows main approaches for face alignment, table 6 shows face representation approaches; table 7 is identification and classification methods. They enumerate the main technical methods in the field of face recognition from the three angles. It should be noted that, face detection has gradually grown into a relatively independent research project. There have been many specialized research papers and reviews [YK02], so this thesis does not give too much explain.

Table 5 Main approaches for face alignment.

Methods	Brief description and main references
Template matching	By calculating associated with the scheduled facial template to locate facial features [BP92]
Peak analysis, Integral projection analysis techniques	Locate the center of eye, mouth and nostrils, etc. [Ka73, BP92]
Snake	Extract facial contour features [KW88, XS94]
Eigenface	Locate face and facial features [TP91]
Deformable template matching	Adjust parabola, hyperbola, etc.model's parameters to match the eyes, mouth, chin, etc. [Yu91, YH92,XS94, CL93]
Optical flow, Vectorize	Using optical flow iterative to estable the corresponding relationship between input face and reference face [Be95]
Elastic graph matching	Through figure deformation, match Gabor point local features, and global geometric structure features[LV93,WF97,KT00,TK01]
ASM	Global statistical model constraints local texture matching results [CT95,LW01,HL01,LY02,YL03,ZG03,SGW03,WA03]
AAM	Optimize the shape and texture statistical model, make model and input match, get the shape and texture [CE98,EC99,CW00,St00]
3D deformable model	Optimize 3D shape, texture, imaging parameters, make synthetic model image best match, get face 3D shape and texture [BV99,RB02,BR02,BT03]

Table 6 Main approaches for face representation.

Face descriptive model	Brief description and main references
Facial geometric structure feature	Parameters such as distance, angle, area, etc. [Ka73, KB76, HK81, BP93, MC92]
Grayscale template	All pixel brightness values concatenate to form vector or matrix [BP92]
PCA	Features obtained after PCA dimensionality reduction [SK87, KS90, TP91, PM94, BH97, MP97,ZC98]
Algebraic features such as singular value	Singular value obtained after SVD decomposition [Ho91, LC93,TT03]
Deformation template	Parabolic, hyperbolic and other parameters of the mathematical model [Yu91, YH92,XS94,CL93]
2D shape model	Spares statistical distribution models feature points(PDM) [CT95,LT94,LW01]
Optical flow model	Correspondence with reference image [Be95]
Texture model regardless of shape	Image model after aligning the sparse feature points and the average shape [LT97, LW01]
Appearance model	Shape and texture through the PCA further model [LT97,LW01]
3D deformable model	3Dshape PCA and Texture PCA [BV99, RB02,BR02, BT03]
Local feature	Local structure information could preserve global topological [PA96]
Elastic properties figure	Feature points' local structure information and its geometrical relationship [LV93,WF97,KT00,TK01]
Gabor, FFT DCT	Different frequency, different types of filters in image to obtain the frequency domain convolution [LY99, LY01,CW02,LW02,LW03,Lee96,Kr00]
Independent component characteristics	Each features have the statistical independence [BL98,DC01,LW99,LW03]
Light cone	Statistical independence between features [GK98,GB01]
Quotient image	The ratio of surface reflectively [SR01,WL04]

Table 7 Main approaches for discrimination and classification.

Discrimination and classification	**Brief description and main references**
Nearest neighbor /K-nearest	The most commonly used method, the literature cannot be enumerated
Artificial neural network	Including self-organizing mapping, BP,DLA,etc. [LO95,PL92,RB98, LG97,LV93]
Nearest feature line method	New distance measure [LL99]
Linear subspace	Each category respectively establish subspace [BH97,GB01,BJ01,BH01,LH01,SG03]
Linear discriminant analysis	[BH96,BH97,CL00,ZC98,ZC00,LW01,LW02,YY01]
Kernel discriminant analysis techniques	[YA00,Ya02,LH02]
Support vector machines	[Ph98,GL00,JM00]
Bayesian decision	Intra-class difference, class difference Gemini space, Bayesian classifier [MP95,MP97,MP00,Mo02,LIU99,WT04]
Elastic graph matching technique	[BL90, LV93,WF97,KT00,TK01]
Hidden Markov model approach	Consider the structure information as timing signal change [Sa93, SY94,Sa94,Ne99]
AdaBoost	Combine the weak classifiers to strong classifier [VJ01,VJo01,ZZ02,LZ04,PS04]
Manifold learning techniques	ISOMAP,LLE,LPP [TS00,RL00]

3.4 Domestic and International Public Face Image Database and Its Performance Evaluation

Face database for algorithm research and development, model training, performance testing and comparison are essential. And the performance evaluation is the important part for the different algorithms performance comparison, specific algorithm improvement, model adjustment and found the problem then propose new algorithm. This section describes the major domestic and international public face image database, and FERET, FRVT face recognition performance evaluation [PM00, PG03]. And it analyses face recognition currently technology and the main challenges.

3.4.1 The major public face image database

Face database for algorithm research and development, model training, performance testing and comparison are essential. Especially in statistical learning dominated today, model training face database significantly affect the accuracy and robustness of the algorithm. Face database's size and properties also determines the rationality and effectiveness of testing result. Brief face database is introduced by following.

(1) FERET face database [PM00]

FERET created the database includes 14,051 pieces of gesture, different lighting conditions grayscale face image. And strictly divided the training set, Gallery, different testing set, etc. it is the most used face database, see: http://www.itl.nist.gov/iad/humanid/ferret/feret_master.html

(2) PIE face database [SB03]

Carnefie Mellon university created it, contains 68 volunteers, 41,368 multi-pose, illumination and facial expression image, the posture and illumination changes are strictly controlled. For detail see: http://www.ri.cmu.edu/projects/proejct_418.html

(3) BANCA face database [SB03]

This face database was created by European BANCA project funding. It contains 208 multi-modal biometrics, covers different image quality, different time periods and other change condition. This face database divides the different training and testing conditions. For detail see: http://www.ee.surrey.uk/research/vssp/banca/

(4) CAS-PEAL face database [GC04]

There are 1,040 Chinese, 99,450 head shoulder images. All images are collected in a special collection environment, covers posture, facial expression, accessories and lighting conditions four major changes. Part of the face image has the background and distance changes. Detail see: http://www.jdl.ac.cn/peal/index.html

(5) AR face database [MB98]

This face database was created by computer vision center in Barcelona, Spain, in 1998. There are 3288 different illumination, expression, occlusion and aging face images from 116 people. For detail see:
http://rvll.ecn.purdue.edu/~aleix/aleix_face_DB.html

(6) ORL face database [SH94]

Created by Cambridge AT&T Labs, contains 400 face images from 40 people. Some volunteer's image include the posture, facial expression and facial ornaments changes. This face database often used in the early, but due to the less change, most of the system recognition rate can reach more than 90%.

(7) XM2VTS Multi-modal biometric database [MM99]

This database includes 295 people in four months, four times recorded the face and voice data. Each collection includes two head rotation six different videos. In addition, 293 people could obtain the 3D model.

(8) MIT face database [TP91]

Created by MIT Media Lab, include 2,592 different pose, illumination and size face images from 16 volunteers.

(9) Yale face database [BH97]

Created by Yale University computation vision and control center, include 165 different illumination, expression and posture images from 15 volunteers.

(10) Yale face database B [GB01]

Contain 5,850 multi-pose, multi-light images from 10 people. The posture and illumination change images are acquired under strictly controlled condition. It is mainly used for the modeling and analysis on the problem of illumination and posture.

(11) PF01 face database [DG01]

Created by South Korean Pohang University, contain 1,751 different light, gesture, and facial expression images from 103.

(12) KFDB face database [HB03]

This database contains total 52.000 images from 1000 Korean; cover 7 different attitudes, 16 different lighting conditions and 5 kinds of expression changes.

In Table 8, we give a comparison of face databases which were used to test the performance of these face recognition algorithms. The description and limitations of each database are given.

Table 8 Comparison of Different Face Databases.

Database	Description	Limitation
AT&T (formerly ORL)	Contains face images of 40 persons, with 10 images of each. For most subjects, the 10 images were shot at different times and with different lighting conditions, but always against a dark background.	(1) Limited number of people (2) illumination conditions are not consistent from image to image. (3) the images are not annotated for different facial expressions, head rotation, or lighting conditions.
Oulu Physics	Includes frontal color images of 125 different faces. Each face was photographed 16 times, using 1 of 4 different illuminants (horizon, incandescent, fluorescent, and daylight) in combination with 1 of 4 different camera calibrations (color balance settings). The images were captured under dark room conditions, and a gray screen was placed behind the participant. The spectral reflectance (over the range from 400 nm to 700 nm) was measured at the forehead, left cheek, and right cheek of each person	(1) Although this database contains images captured under a good variety of illuminant colors, and the images are annotated for illuminant, there are no variations in the lighting angle. (2) all of the face images are basically frontal (with some variations in pose angle and distance from the camera)

	with a spectrophotometer. The spectral sensitivities of the R, G and B channels of the camera, and the spectral power of the four illuminants were also recorded over the same spectral range.	
XM2VTS	Consists of 1000 GBytes of video sequences and speech recordings taken of 295 subjects at one-month intervals over a period of 4 months (4 recording sessions). Significant variability in appearance of clients (such as changes of hairstyle, facial hair, shape and presence or absence of glasses) is present in the recordings. During each of the 4 sessions a "speech" video sequence and a "head rotation" video sequence was captured. This database is designed to test systems designed to do multimodal (video + audio) identification of humans by facial and voice features.	It does not include any information about the image acquisition parameters, such as illuminate on angle, illumination color, or pose angle.
Yale	Contains frontal grayscale face images of 15 people, with 11 face images of each subject, giving a total of 165 images. Lighting variations include left-light, center-light, and right-light. Spectacle variations include with-glasses and without-glasses. Facial expression variations include normal, happy, sad, sleepy, surprised, and wink.	(1) limited number of people (2) while the face images in this database were taken with 3 different lighting angles (left, center, and right) the precise positions of the light sources are not specified. (3) since all images are frontal, there are no pose angle variations. (4) Environmental factors (such as the presence or absence of ambient light) are also not described.
	Contains grayscale images of 10	(1) Limited number of Subjects.

Yale B	subjects with 64 different lighting angles and 9 different poses angles, for a total of 5760 images. Pose 0 is a frontal view, in which the subject directs his/her gaze directly into the camera lens. In poses 1, 2, 3, 4, and 5 the subject is gazing at 5 points on a semicircle about 12 degrees away from the camera lens, in the left visual field. In poses 6, 7, and 8 the subject is gazing at 3 different points on a semicircle about 24 degrees away from the camera lens, again in the left visual field. The images were captured with an overhead lighting structure which was fitted with 64 computer controlled xenon strobe lights. For each pose, 64 images were captured of each subject at a rate of 30 frames/sec, over a period of about 2 seconds.	(2) The background in these images is not homogeneous, and is cluttered. (3) The 9 different pose angles in these images were not precisely controlled. Where the exact head orientation (both vertically and horizontally) for each pose was chosen by the subject.
MIT	Contains 16 subjects. Each subject sat on a couch and was photographed 27 times, while varying head orientation. The lighting direction and the camera zoom were also varied during the sequence. The resulting 480 x 512 grayscale images were then filtered and sub sampled by factors of 2, to produce six levels of a binary Gaussian pyramid. The six “pyramid levels” are annotated by an X-by-Y pixel count, which ranged from 480x512 down to 15x16.	(1) Although this database contains images that were captured with a few different scale variations, lighting variations, and pose variations, these variations were not very extensive, and were not precisely measured. (2)There was also apparently no effort made to prevent the subjects from moving between pictures.
CMU Pose, Illumination, and Expression (PIE)	contains images of 68 subjects that were captured with 13 different poses, 43 different illumination conditions, and 4 different facial expressions, for a total of 41,368 color images with a resolution of	(1) There was clutter visible in the backgrounds of these images. (2) The exact pose angle for each image is not specified.

	640 x 486. Two sets of images were captured － one set with ambient lighting present, and another set with ambient lighting absent.	

3.4.2 FERET Testing

Considering the importance of the face recognition on the military, security and law, etc, U.S.Department of Defense anti-drug technology developed existing face recognition system technology project through DARPA fund. From 1993 to 1997, three times face recognition performance evaluation were organized (respectively in 1994, 1995, 1996, and there was a supplementary test in 1997) [PM00]. Test result is considered to reflect the highest academic level of face recognition technology at that time. According to the FERET'96 test report published in IEEE Tranc.On PAMI, the University of Southern California's elastic graph matching technology, University of Maryland's subspace discriminant analysis method, Massachusetts Institute of Technology's Bayesian methods have best recognition performance.

3.4.3 FRVT2000 and FRVT2002 testing

After FERET testing, there have been many commercial face recognition systems soon. On the other hand, U.S security military and law departments began to pay more attention to the application of face recognition technology. In order to compare performance of business practical systems, apply detailed face recognition system's performance information for the application department, U.S.DARPA, Dos, FBI and NIST and many other institutions funded to test the recognition products' evaluation on commercial projects twice in 2000 and 2002.

There are eight commercial face recognition system participated FRVT 2000 testing, but only five were completed all the tests within the given time; they are Visionics, Lau, Miros, C-VIS and Banque-Tec.

FRVT2000 added compression, distance, expression, illumination, storage media, posture, resolution and aging testing based on the FERET.

The results showed that the adaptability of these systems of distance, illumination, posture and aging were poor, the greater the change, the greater performance drop.

And FRVT2002 testing [PG03] is more detailed. Most of well-known face recognition commercial systems took part in the evaluation. This testing was divided into high computation intensity (HCInt) and moderate computation intensity (MCInt) two parts.

3.5 Some Open Problems and Possible Technology Trends

3.5.1 Some Open Problems

After 30 years of development, especially in nearly a decade of research, face recognition technology has made great progress. The best face recognition system in the registration and certification of environmental conditions more consistent has been able to achieve a satisfactory result. However, this does not mean that human face recognition technology is already very mature. On the contrary, because of greater amounts of face recognition application system need to be more greatly scale face database, Camera environment uncontrollable, users do not cooperate. The best recognition system under such conditions, the performance decline very quickly. Therefore, the existing face recognition systems have not yet mature. Especially need to be targeted to solve under the condition of non-ideal camera (illumination changes, background, camera equipment differences) and the user does not cooperate (perspective changes, expression, decorations and even makeup) identify performance problems.

As shown in Fig.14 the changes of the factors in different application systems will have different appear. They greatly affect the performance of practical recognition system. It led the recognition system performance to decline.

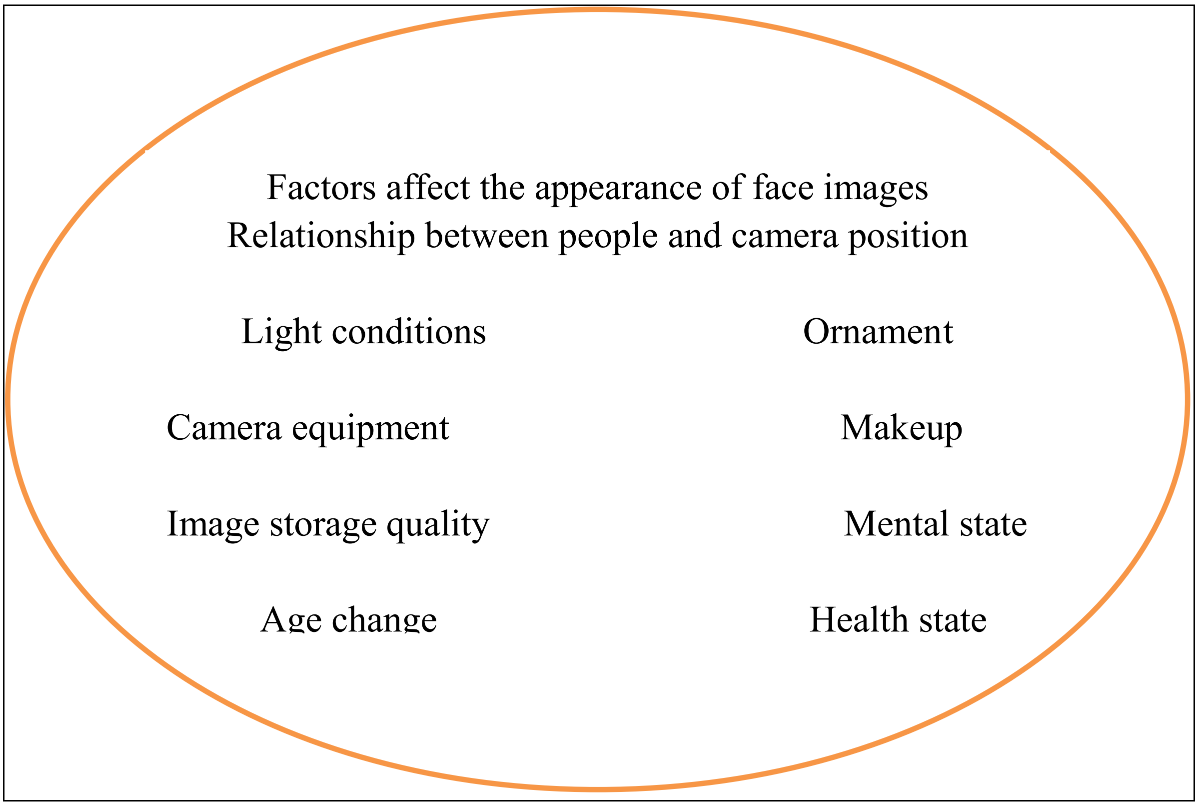


Fig. 14 Factors affect the appearance of face images.

3.5.2 Possible Technology Trends

At present, the main obstacle to practical face recognition is under the conditions of the non-ideal acquisition to decline the recognition performance rapidly. This problem is caused by both the stability problem of signal data acquisition, also the robustness problem of the facial characteristics acquisition. At the same time it is closely related to the generalization ability of the core identification algorithm.

Therefore, this paper argues that to solve these problems needs to be calculation model to explore the nature of face recognition from different aspects, such as signal, characteristic and symbol. Table 9 shows the dozen technology trends. Among them, multiple cameras fusion recognition technology, Sequence of image analysis, Human face modeling method based on nonlinear manifold learning, 3D deformation model and the 3D facial recognition technology, facial features accurate registration, Robust face said, Generalization ability on various transformations robust classification algorithm and so on research topics are particular concern.

Table 9 Some new trends in AFR.

Signal level	Characteristic level	Symbol level
Multi-camera device integration	Facial features accurately	statistical learning methods
Sequential image analysis	Face model manifold learning	Massive data learning
Camera automatically correct	3D face shape recovery	Generalization ability analysis
Adaptive preprocessing	Based on the 3D information identification	Multiple classifier fusion decision
Development of new sensor	Illumination pose 3D model	classifier robust to the change
	Multiple feature fusion strategies	
	The optimal discriminant feature extraction	
	Mis-alignment robust representation	

3.6 Summarize Development Situation

Automatic face recognition research is in the ascendant. This chapter from several different angles to explore the development of face recognition research situation. Automatic face recognition research after nearly 40 years of research and development has made great progress in recent years. By far the best performance of face recognition systems have reached more than 90%, and have got some application in limited range, under the occasion of face database size about 1000 people, ideal imaging conditions and user cooperation. But this does not mean that face recognition is a mature technical problem. Instead, face recognition research is still facing many challenging problems. Objectively speaking, under the condition of many applications, the best recognition system recognition rate is often less than 50%. That is why until now there are no typical facial recognition successful cases and difficult to promote.

Face recognition technology is a challenging problem in the field of image analysis and computer vision because of its various applications. Algorithm research has been conducted vigorously, and big progress has been gotten, encouraging results have been obtained. Current face recognition system has reached a certain degree of maturity when operating under constrained conditions. However, they are far from achieving the ideal performance in various situations that are encountered by applications in practical. The ultimate goal of face recognition researchers is to enable computers to emulate the human vision system to recognize human being.

CHAPTER IV

EYE LOCATION AND IMPROVED FACE DETECTION ALGORITHM BASED ON ADABOOST

4.1 Overview of Eye Location and Face Detection

The eyes are the one of the most important organs of a face including a lot of useful features. Precise eye location technology could be applied in many fields such as face alignment, facial features detection, face recognition and head pose estimation etc. Therefore, the detection of the eyes is a vital component in computer vision and pattern recognition.

This paper proposes an eye location method based on the HSV color space model using template matching. At first, we describe an implementation for skin detection which relies on the H channel to characterize the skin colors range, and determine the possible face region. Then we manually extract an average eye template using the human eye's sample images, and finally in the face region, locate the eyes using this average template. As eye template matching, the rectangular region of the eye which confirmed from the skin region is just searched. Compared to other template matching methods that search for the human eye in whole face region, the proposed method saves on the matching time by avoiding the impact of the mouth and nose in the process of positioning. Undoubtedly, this method enhances the accuracy of eye detection.

Face feature extraction is the first step in face recognition where the main goal is to characterize the face with the least amount of characteristics.

At the same time, the characteristics preserve the discriminative ability among different faces. There are a lot of researches showing how significant the influence is using different facial feature extraction method for face recognition. The face region detection should be preceded before extracting facial features.

4.2 Template Matching and Skin Detection Using HSV Space

First, the RGB image was converted to HSV color space. The skin in channel H is characterized by values between 0 and 50. After some tests we proposed to use the channel H with values ranging between 0 and 20 according to our database. Fig.15 shows the same image converted from RGB to HSV color space. Fig.16 is an intermediary image, where all pixels classified as skin were set to value 255, and non-skin pixels was fixed to 0.

In the Fig.16 there are many noises, in the classification of pixels like skin and non-skin. Next step minimizes the effects of the noise pixels using a 5x5 median filter. Finally, only skin regions are represented as white pixels. The result is shown in Fig. 17. The binary image aims to retain the most useful part of image. In many cases, this is a necessary preprocess before image analysis, feature extraction and pattern recognition.

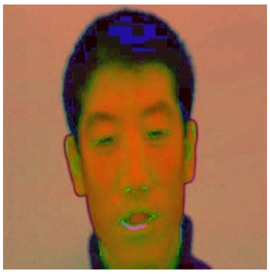


Fig. 15 Same Image in HSV.

Fig. 16 An Intermediary.

Fig. 17 The Result of Skin Detection.

4.2.1 Eye Template Matching

In this paper, the eye template is constructed as follows:

First five images are selected from the face database. They have same size; then median filter to eliminate the noise and hologram equalization to reduce the side-effect of illumination are applied to the images. Finally the same size left and right eyes are obtained manually from the processed image, the synthetic eye template is determined by the average of left and right eyes respectively. Then the synthetic eye template is created. The final eye template is shown as Fig.18.

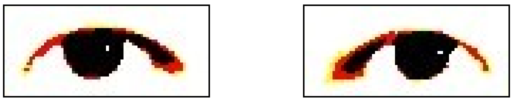


Fig. 18 Left and Right Synthetic Eye Templates.

OpenCV has functions to perform template matching with several methods depends on the method parameter. It slides through original image, compares the overlapped patches of size w×h against template using the specified method and stores the comparison results. Here are the formulas for the different comparison methods. I denotes image, T is template and R is result. The summation is done over template and the image patch: x’=0…w-1, y’ =0…h-1.

Method 1 = CV_TM_SQDIFF

$$R(x,y)=\sum_{x',y'}[T(x',y')-I(x+x',y+y')]^2 \tag{4.1}$$

Method 2 =CV_TM_SQDIFF_NORMED

$$R(x,y)=\frac{\sum_{x',y'}(T(x',y')-I(x+x',y+y'))^2}{\sqrt{\sum_{x',y'}T(x',y')^2\cdot\sum_{x',y'}I(x+x',y+y')^2}} \tag{4.2}$$

Method 3 = CV_TM_CCORR

$$R(x,y)=\sum_{x',y'}(T(x',y')\cdot I(x+x',y+y')) \tag{4.3}$$

Method 4 = CV_TM_CCORR_NORMED

$$R(x,y)=\frac{\sum_{x',y'}(T(x',y')-I'(x+x',y+y'))}{\sqrt{\sum_{x',y'}T(x',y')^2\cdot\sum_{x',y'}I(x+x',y+y')^2}} \tag{4.4}$$

Method 5 = CV_TM_CCOEFF

$$R(x,y)=\sum_{x',y'}[T'(x',y')\cdot I(x+x',y+y')] \tag{4.5}$$

Where $T'(x',y')=T(x',y')-\frac{1}{(w\cdot h)\cdot\sum_{x'',y''}T(x'',y'')}$

$$I'(x+x',y+y')=I(x+x',y+y')-\frac{1}{(w\cdot h)\cdot\sum_{x'',y''}T(x'',y'')}$$

Method 6 = CV_TM_CCOEFF_NORMED

$$R(x,y)=\frac{\sum_{x',y'}(T'(x',y')\cdot I'(x+x',y+y'))}{\sqrt{\sum_{x',y'}T'(x',y')^2\cdot\sum_{x',y'}I'(x+x',y+y')^2}} \tag{4.6}$$

After the function finishes the comparison, the best matches can be found as global minimums (CV_TM_SQDIFF) or maximums (CV_TM_ CCORR and CV_TM_CCOEFF) using the MinMaxLoc function. In the case of a color image, template summation in the numerator and each sum in the denominator are done over all of the channels. In this paper, experimental results are better when using the method 1.

4.2.2 Face Region Normalization

Fig.19 shows the result of the eye region recognition. Firstly, the range of eye location can be reduced to the first part of the rectangular area in according to the distributed character of face region, as eye template matching, the rectangular face region is just searched; the premise is accurate detection of the face region. The matching efficiency and error are both improved.

Fig. 19 Rectangular of Eye Region.

Secondly, the eye has obvious symmetry, so the first part of the face region can be divided into the left side and the right side, and then the template matching is executed

4.3 Summaries AdaBoost Algorithm and Proposed Improved AdaBoost Algorithm for Face Detection

Face detection technology as an important part of face recognition has high research and application value. In 2001 the AdaBoost algorithm was applied to face detection by Paul Viola and Michael Jones. The AdaBoost is an algorithm for constructing a strong classifier as linear combine of weak classifier trained by different training sets. The classifiers can be weak (i.e., display a substantial error rate), but their performance is not random (resulting in an error rate of 0.5 for binary classification), they will improve the final model. Fig. 20 shows the flowchart of face detection.

Even classifiers with an error rate higher than would be expected from a random classifier will be useful, since they will have negative coefficients in the final linear combination of classifiers and hence behave like their inverses. At the beginning, each sample has the same corresponding weight. The weight of examples H1 which are the misclassified is increased, and the weight of the correct classified examples is reduced. Therefore, the misclassified samples are prominent, and a new sample distribution U2 is found. After T weak classifiers, boost up these T weak classifiers by a certain weight, then get the strong classifier ultimately. The training process

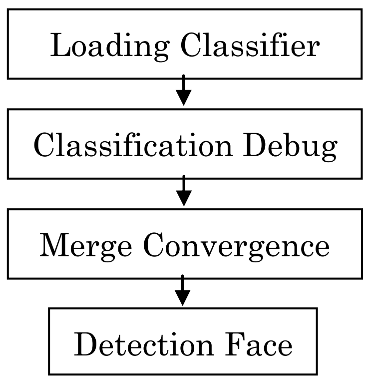


Fig. 20 Face detection flow chart.

is divided into three steps: first extract the Haar characteristics; then convert the Haar characteristics into the corresponding weak classifiers;

Finally choose the optimal weak classifier from a large number of weak classifiers. In this section, an improved training algorithm for AdaBoost is proposed to bring down the complexity of human face detection. Two methods are adopted to accelerate the training: (1) A method to solve the parameters of a single weaker classifier is proposed, making the training speed is higher than probability method; (2) a double threshold decision for a single weaker classifier is introduced, and the number of weaker classifier in the AdaBoost system is reduced. Based on the simplified detector, both the training time and the detecting time could be reduced.

4.4 Experiments and Results

4.4.1 Eye Location Experimental Results

In this section, we will present the experimental results of our algorithm. Binary images converted from original color images are shown in Fig. 21.

We conducted experiments using 50 images without spectacles for testing. The success rate of proposed method is 96%. Fig. 22 shows example of the image for which the proposed method could correctly detect the both eyes. The eyes are mainly located in the half of upper face region.

Fig. 21 Some Examples for Binary Faces without Spectacles.

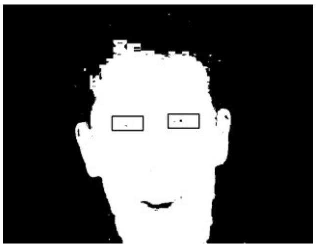


Fig. 22 Results of eye detection without Spectacles.

The searching process is applied in the upper half of the face region. This could avoid the error matching among eyes, mouth and nose. The following results show that the proposed method could correctly locate the eye part, regardless of the facial expression.

There are some error recognitions, as Fig. 25. And it doesn't have good performance for the faces with spectacles.

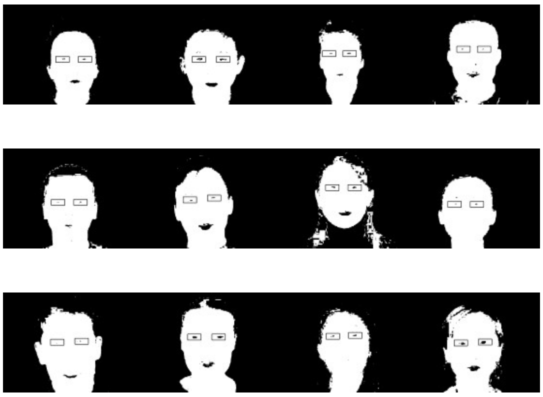


Fig. 23 Some Results of Eye Location with Expressionless Images.

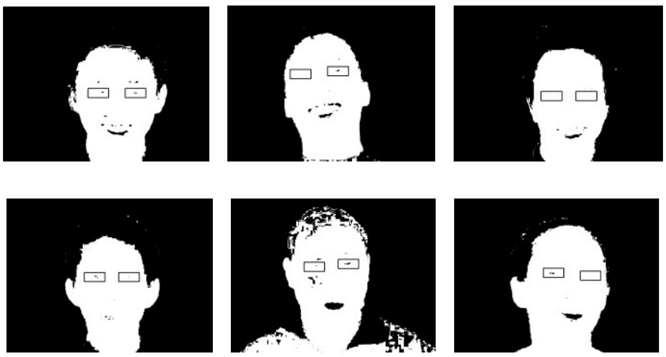


Fig. 24 Results of Expressive Images, the Original Images of These Examples Expressing Various Expressions.

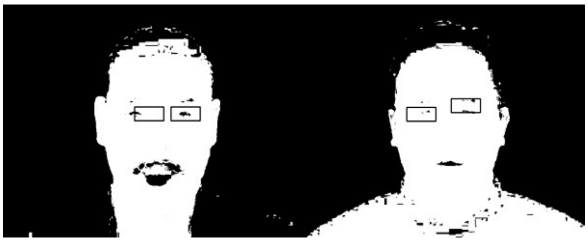


Fig. 25 Error Recognition Examples.

Fig. 26 Detection results using AdaBoost.

4.4.2 Face Detection Experimental Results

The experimental results show that the proposed algorithm obtained more accurate testing results, and it can simplify the system structure which reduced the training time, speed up about 1.5 times. Furthermore the proposed algorithm has multi-resolution analysis ability. Fig. 26 shows some face detection results.

One of the fundamental techniques that enable such natural human computer interaction is face detection. Face detection is the step stone to all facial analysis algorithms, including face alignment, face modeling, face relighting, face recognition, head pose tracking, facial expression tracking/recognition, gender/age recognition, and many more.

We use the Ren-FEdb video database [TK06] collected from 2005 to 2008 including 1,728 videos taken for 96 persons. One has 6 different kind of expression and each expression is to test. The training set should be chosen representatively and attempt to include different expression variation.

CHAPTER V

PRIMARILY STUDIED WAVELET BASED FEATURE EXTRACTION AND SUPPORT VECTOR MACHINES

5.1 Wavelet Transform Analysis Method

Wavelet transform method is an increasingly popular tool in image processing and computer vision. Wavelet transform has nice features of space frequency localization and mustier solutions. The main reasons for Wavelet transforms lie in its complete theoretical framework, the great flexibility for choosing bases and the low computational complexity. Wavelets decompose complex signals into sums of basic functions in this respect they are similar to other discrete image transforms. Not only there two big classes of wavelet transform continuous and discrete - but discrete transform can be redundant, or orthogonal. Each category contains innumerable possibilities, Daubechies wavelets alone constituting a very big class.

5.1.1 Formal Definition of Wavelet Transform

The wavelet transform is similar to the Fourier transform (or much more to the windowed Fourier transform) with a completely different merit function. The main difference is this: Fourier transform decomposes the signal into sins and cosines, i.e. the functions localized in Fourier space; in contrary the wavelet transform uses functions that are localized in both the real and Fourier space. Generally, the wavelet transform can be expressed by the following equation:

$$F(a,b) = \int_{-\infty}^{\infty} f(x)\varphi^{*}_{(a,b)}(x)dx \quad (5.1)$$

where the * is the complex conjugate symbol and function ψ is some function. This function can be chosen arbitrarily provided that obeys certain rules.

As it is seen, the Wavelet transform is in fact an infinite set of various transforms, depending on the merit function used for its computation. This is the main reason, why we can hear the term "wavelet transforms" in very different situations and applications. There are also many ways how to sort the types of the wavelet transforms. Here we show only the division based on the wavelet orthogonally. We can use orthogonal wavelets for discrete wavelet transform development and non-orthogonal wavelets for continuous wavelet transform development. These two transforms have the following properties:

(1) The discrete wavelet transform returns a data vector of the same length as the input is. Usually, even in this vector many data are almost zero. This corresponds to the fact that it decomposes into a set of wavelets (functions) that are orthogonal to its translations and scaling. Therefore we decompose such a signal to a same or lower number of the wavelet coefficient spectrum as is the number of signal data points. Such a wavelet spectrum is very good for signal processing and compression, for example, as we get no redundant information here.

(2) The continuous wavelet transform in contrary returns an array one dimension larger than the input data. For a 1D data we obtain an image of the time-frequency plane. We can easily see the signal frequencies evolution during the duration of the signal and compare the spectrum with other signals spectra. As here is used the non-orthogonal set of wavelets, data are correlated highly, so big redundancy is seen here. This helps to see the results in a more humane form.

5.1.2 Discrete Wavelet Transform

The discrete wavelet transform (DWT) is an implementation of the wavelet transform using a discrete set of the wavelet scales and translations obeying some defined rules. In other words, this transform decomposes the signal into mutually orthogonal set of wavelets, which is the main difference from the continuous wavelet transform (CWT), or its implementation for the discrete time series sometimes called discrete-time continuous wavelet transform (DT-CWT).

The wavelet can be constructed from a scaling function which describes its scaling properties. The restriction that the scaling functions must be orthogonal to its discrete translations implies some mathematical conditions on them which are mentioned everywhere, e.g. the dilation equation

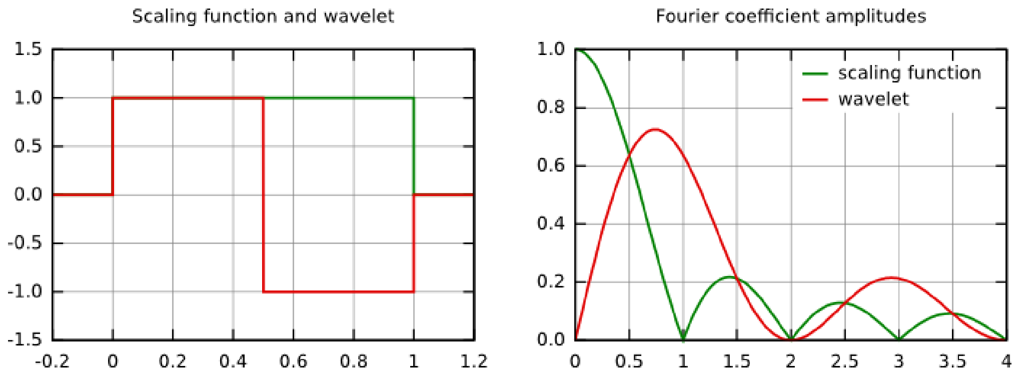
$$\emptyset(\mathrm{x}) = \sum_{k=-\infty}^{\infty} a_k \emptyset(S_x - k) \tag{5.2}$$

where S is a scaling factor (usually chosen as 2). Moreover, the area between the function must be normalized and scaling function must be orthogonal to its integer translations, i.e.

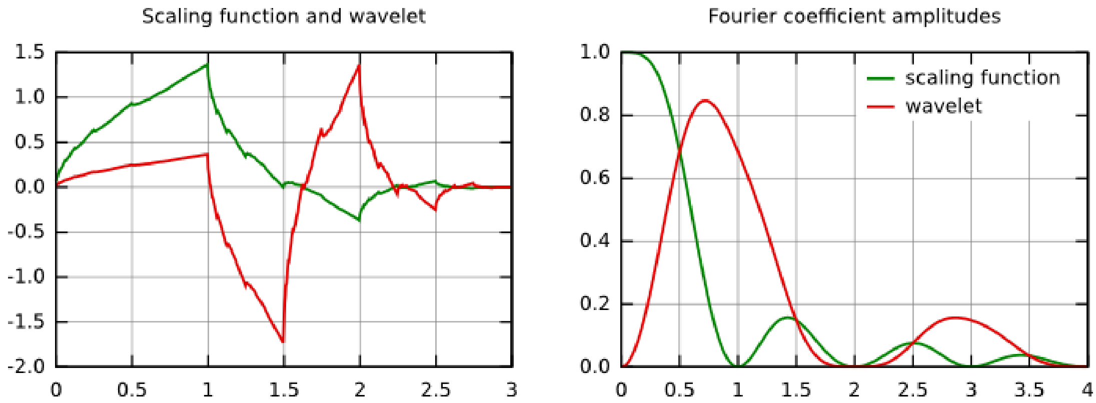
$$\int_{-\infty}^{\infty} \emptyset(x)\emptyset(x+l)dx = \delta_{o,l} \tag{5.3}$$

After introducing some more conditions (as the restrictions above does not produce unique solution) we can obtain results of all these equations, i.e. the finite set of coefficients a_k that define the scaling function and also the wavelet. The wavelet is obtained from the scaling function as N where N is an even integer. The set of wavelets then forms an orthonormal basis which we use to decompose the signal. Note that usually only few of the coefficients a_k are nonzero, which simplifies the calculations.

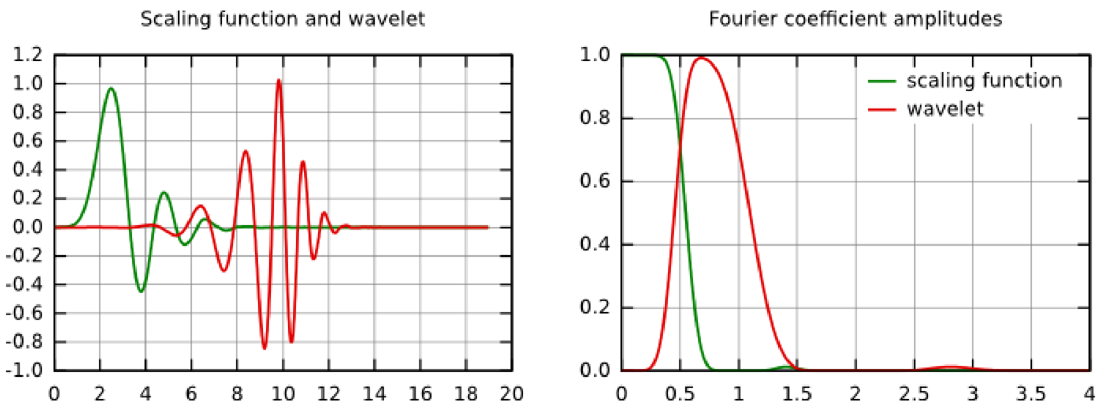
In the following figure, some wavelet scaling functions and wavelets are plotted. The most known family of orthonormal wavelets is the family of Daubechies. Her wavelets are usually denominated by the number of nonzero coefficients a_k, so we usually talk about Daubechies 4, Daubechies 6, etc. wavelets. Roughly said, with the increasing number of wavelet coefficients the functions become smoother. See the comparison of wavelets Daubechies 4 and 20 below. Another mentioned wavelet is the simplest one, the Haar wavelet, which uses a box function as the scaling function.



Haar scaling function and wavelet (left) and their frequency content (right).



Daubechies 4 scaling function and wavelet (left) and their frequency content (right).



Daubechies 20 scaling function and wavelet (left) and their frequency content (right).

There are several types of implementation of the DWT algorithm. The oldest and most known one is the Mallat (pyramidal) algorithm. In this algorithm two filters – smoothing and non-smoothing one – are constructed from the wavelet coefficients and those filters are recurrently used to obtain data for all the scales. If the total number of data $D = 2N$ is used and the signal length is L, first $D/2$ data at scale $L/2N - 1$ are computed, then $(D/2)/2$ data at scale $L/2N - 2$, … up to finally obtaining 2 data at scale $L/2$. The result of this algorithm is an array of the same length as the input one, where the data are usually sorted from the largest scales to the smallest ones.

Within Gwyddion the pyramidal algorithm is used for computing the discrete wavelet transform. Discrete wavelet transform in 2D can be accessed using DWT module.

Discrete wavelet transform can be used for easy and fast denoising of a noisy signal. If we take only a limited number of highest coefficients of the discrete wavelet transform spectrum, and we perform an inverse transform (with the same wavelet basis) we can obtain more or less denoised signal. There are several ways how to choose the coefficients that will be kept. Within Gwyddion, the universal thresholding, scale adaptive thresholding and scale and space adaptive thresholding is implemented. For threshold determination within these methods we first determine the noise variance guess given by

$$\hat{\sigma} = \frac{Median\,|Y_{ij}|}{0.6745} \tag{5.4}$$

where Y_{ij} corresponds to all the coefficients of the highest scale subband of the decomposition (where most of the noise is assumed to be present). Alternatively, the noise variance can be obtained in an independent way, for example from the AFM signal variance while not scanning. For the highest frequency subband (universal thresholding) or for each subband (for scale adaptive thresholding) or for each pixel neighbourhood within subband (for scale and space adaptive thresholding) the variance is computed as

$$\hat{\sigma}_Y^2 = \frac{1}{n^2} \sum_{i,j=l}^{n} Y_{ij}^2 \tag{5.5}$$

Threshold value is finally computed as

$$T(\hat{\sigma}x) = \frac{\hat{\sigma}^2}{\hat{\sigma}x} \tag{5.6}$$

where

$$\hat{\sigma}x = \sqrt{\max(\hat{\sigma}_Y^2 - \hat{\sigma}^2, 0)} \tag{5.7}$$

When threshold for given scale is known, we can remove all the coefficients smaller than threshold value (hard thresholding) or we can lower the absolute value of these coefficients by threshold value.

5.1.3 Continuous Wavelet Transform

Continuous wavelet transform (CWT) is an implementation of the wavelet transform using arbitrary scales and almost arbitrary wavelets. The wavelets used are not orthogonal and the data obtained by this transform are highly correlated. For the discrete time series we can use this transform as well, with the limitation that the smallest wavelet translations must be equal to the data sampling. This is sometimes called Discrete Time Continuous Wavelet Transform (DT-CWT) and it is the most used way of computing CWT in real applications.

In principle the continuous wavelet transform works by using directly the definition of the wavelet transform, i.e. we are computing a convolution of the signal with the scaled wavelet. For each scale we obtain by this way an array of the same length *N* as the signal has. By using *M arb*itrarily chosen scales we obtain a field $N \times M$ *t*hat represents the time-frequency plane directly. The algorithm used for this computation can be based on a direct convolution or on a convolution by means of multiplication in Fourier space.

The choice of the wavelet that is used for time-frequency decomposition is the most important thing. By this choice we can influence the time and frequency resolution of the result. We cannot change the main features of WT by this way (low frequencies have good frequency and bad time resolution; high frequencies have good time and bad frequency resolution), but we can somehow increase the total frequency of total time resolution. This is directly proportional to the width of the used wavelet in real and Fourier space. If we use the Morlet wavelet for example (real part – damped cosine function) we can expect high frequency resolution as such a wavelet is very well localized in frequencies. In contrary, using Derivative of Gaussian (DOG) wavelet will result in good time localization, but poor one in frequencies.

5.2 Support Vector Machines

SVM is a learning technique that is considered an effective method for general purpose pattern recognition because of its high generalization performance without the need to add other knowledge. Intuitively, given a set of points belonging to two classes, a SVM finds the hyper plane that separates the largest possible fraction of points of the same class on the same side, while maximizing the distance from either class to the hyper-plane. According to, this hyper plane is called Optimal Separating Hyper plane (OSH) which minimizes the risk of misclassifying not only the examples in the training set but also the unseen example of the test set. SVM is suitable for average size face recognition systems because normally those systems have only a small number of training samples.

The original SVM algorithm was invented by Vladimir N. Vapink and the current standard incarnation was proposed by Vapnik and Cortes in 1995. The SVM can be used in the pattern recognition and regression estimation. In recent years, the SVM has become a research focus of artificial intelligence. It belongs to machine learning, pattern recognition and artificial neural network, and other disciplines. It has obvious advantages compared with existing theories and methods: (1) SVM is a classification algorithm based on the structural risk minimization principle. It has achieved higher generalization ability using the limited training samples than other classification algorithms. SVM obtains the small error on the limited training samples, which could be guaranteed on the independent test samples; (2) SVM algorithm is a convex optimization problem, the local optimal solution must be a global optimal solution. In addition, the scale of the optimization problem is only related to the sample number, and has nothing to do with the sample dimension. It is very suitable for solving the problem which has the high dimension and fewer samples, such as face recognition.

5.2.1 Linear SVM

Given some training data D, a set of n points of the form

$$D = \{(x_i, y_i) | x_i \in R^p, y_i \in \{-1,1\}\}_{i=1}^{n} \tag{5.8}$$

where the y_i is either 1 or −1, indicating the class to which the point x_i belongs. Each x_i is a p-dimensional real vector. We want to find the maximum-margin hyperplane that divides the points having y_i =1from those having y_i = -1. Any hyperplane can be written as the set of points x satisfying

$$w \cdot x - b = 0 \tag{5.9}$$

where • denotes the dot product and w the normal vector to the hyperplane. The parameter $\frac{b}{\|w\|}$ determines the offset of the hyperplane from the origin along the normal vector w.

If the training data are linearly separable, we can select two hyperplanes in a way that they separate the data and there are no points between them, and then try to maximize their distance. The region bounded by them is called "the margin". These hyperplanes can be described by the equations $w \cdot x - b = 1$ *and* $w \cdot x - b = -1$.

By using geometry, we find the distance between these two hyperplanes is $\frac{2}{\|w\|}$, so we want to minimize $\|w\|$. As we also have to prevent data points from falling into the margin, we add the following constraint: for each i either $w \cdot x_i - b$ 》1 for xi of the first class or $w \cdot x_i - b$ 》1 for xi of the second.

This can be rewritten as:

$$y_i(w \cdot x_i - b) \geq 1, \text{for all } 1 \leq i \leq n \tag{5.10}$$

We can put this together to get the optimization problem:
Minimize (in w,b)

$$\|w\|$$

Subject to (for any $i=1,\ldots,n$) $y_i(w \cdot x_i - b) \geq 1$.

5.2.2 Nonlinear Classification

The original optimal hyperplane algorithm proposed by Vapnik in 1963 was a linear classifier. However, in 1992, Bernhard E. Boser, Isabelle M. Guyon and Vladimir N. Vapnik suggested a way to create nonlinear classifiers by applying the kernel trick (originally proposed by Aizerman et al.[AM64]) to maximum-margin hyperplanes.[BB92] The resulting algorithm is formally similar, except that every dot product is replaced by a nonlinear kernel function. This allows the algorithm to fit the maximum-margin hyperplane in a transformed feature space. The transformation may be nonlinear and the transformed space high dimensional; thus though the classifier is a hyperplane in the high-dimensional feature space, it may be nonlinear in the original input space.

If the kernel used is a Gaussian radial basis function, the corresponding feature space is a Hilbert space of infinite dimensions. Maximum margin classifiers are well regularized, so the infinite dimensions do not spoil the results. Some common kernels include:

- Polynomial (homogeneous): $k(x_i,x_j) = (x_i,x_j)^d$
- Polynomial (inhomogeneous): $k(x_i,x_j) = (x_i,x_j+1)^d$
- Gaussian radial basis function: $k(x_i,x_j) = \exp(-\gamma\|x_i - x_j\|^2)$

  for $\gamma>0$ Sometimes parameterized using $\gamma = \frac{1}{2\sigma^2}$
- Hyperbolic tangent: $k(x_i,x_j) = \tanh(kx_i,x_j+c)$, for some (not every) $k>0$ and $c<0$

The kernel is related to the transform $\varphi(x_i)$ by the equation$k(x_i,x_j) = \varphi(x_i)\cdot\varphi(x_j)$. The value w is also in the transformed space, with$w = \sum_i a_i y_i \varphi(x_i)$. Dot products with w for classification can again be computed by the kernel trick, i.e. $w\cdot\varphi(x) = \sum_i a_i y_i k(x_i,x)$.

However, there does not in general exist a value w' such that $w \cdot \varphi(x) = k(w', x)$.

5.3 Proposed Method based on Wavelet Transform Method and SVM

In this paper, we chose wavelet decomposition to extract facial features, because wavelet decomposition decomposes the signal into two parts: low and high frequency L_1 and H_1. In two level decomposition, the subimage of low frequency is decomposed into low frequency L2 and high frequency H2. For two dimensional signals like face images, wavelet decomposition is not complete after the row transformation and rank transformation. Wavelet decomposition is not only diminished but the expression variation also reduced the image size in the low frequency subimage.

5.3.1 Facial Feature Extraction based on Wavelet Transformation Method

Low frequency subimages of two faces of the same person after wavelet decomposition. (a) Original images with different facial expression, image size 64×64. (b) The results of two level wavelet decomposition. (c) Reconstructed images, image size 16×16.

In summary, this paper proposes the facial feature extraction as follows:

- Select the wavelet basis db4 in the Daubechies wavelet and apply level two wavelet decomposition that is conducted to the standard face region. Get low frequency subimage I_1 and low frequency subimage I_2.
- I_1 image matrix is arranged into the vector V_1 according to the row or rank order.
- Obtain the vector V_h through horizontal direction grayscale integral projection applied to image H_1; the image I_1 is divided into two parts: upper and lower, then seeking the vertical direction grayscale integral projection of the previous two part images V_{v1} and V_{v2}, and combine V_h, V_{v1} and V_{v2} into another vector V_2.

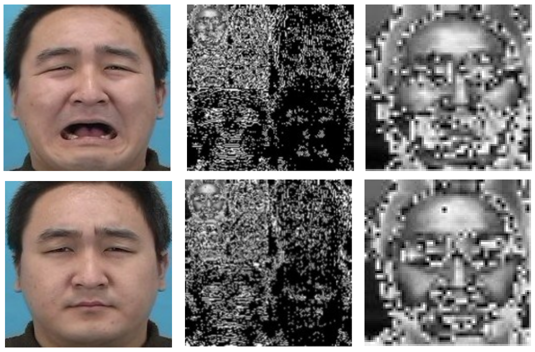


Fig. 27 Examples of facial images for two-dimensional wavelet decomposition with depth 2.

Finally V_1 and V_2 will be combined into face feature vector, x.

The extracted features from human images by wavelet decomposition are less sensitive to facial expression variations as shown in Fig.27.

Despite of the low frequency subimage after wavelet decomposition losing the high frequency component, but it still has the ability of distinguishing different human faces. The wavelet analysis has obtained broad application and development in signal process for the above-mentioned reason.

5.3.2 Classification based on SVM

In support vector machines for classification, the structure of the complex depends on the number of support vectors, instead of the characteristic dimension of the space, which is effective to solve the nonlinear and curse dimensionality problem in machine learning. Fig.28 shows the classification schemes of SVM diagram.

SVM is developed from the theory of linearly separable optimal hyper plane. The basic idea of the two classes SVM is that first transform the input sample space into feature space by using non-linear transformation; then searches the optimum classification hyper plane in this feature space. This non-linear transformation is obtained by defining the appropriate kernel function.

The two classes' samples which are closest to the optimum linearity classification hyper plane are called SVM. Considering two linearly separable classes : assume the training data (x_i, y_i), $i = 1, \ldots, l$,

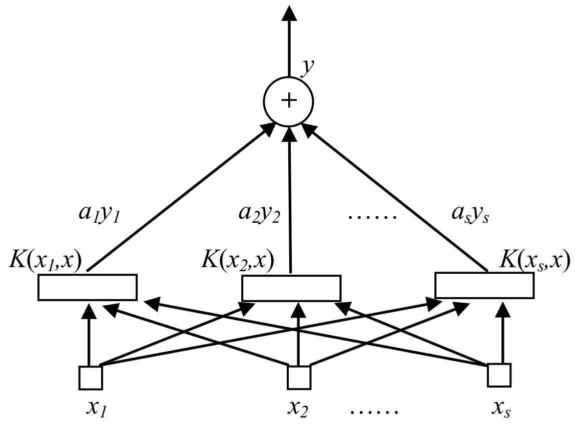


Fig. 28 Classification schemes of SVM.

$x_i \in \{+1, -1\}$ can be separated by a hyper plane $(w \cdot x) + b = 0$ with no mistake. According to the intuitive speculation, the classification hyper plane which has the largest distance with two type's samples will get the best generalization ability (generation).

Optimal hyper plane is determined by the nearest sample points, and no relationship with the other samples. You can use the following form to describe the hyper plane of sample interval: $(w \cdot x) + b = 0$, $\|w\| = 1$, so it is $y = 1$, if $(w \cdot x) + b \geq g(x)$; $y = -1$, $(w \cdot x) + b \leq g(x)$.

Input vectors are $x = (x_1, x_2, \ldots, x_s)$, output result is expressed as $y = \sum_{i=1}^{s} a_i y_i K(x_i, x) + b$, the weight is $w_i = a_i y_i$, nonlinear transformation based on support vectors is $x_1, x_2, \ldots, x_s$. SVM mainly processes the two class classify captions problem. Multi-class problem can be processed through the combination of some two classes support vector machines. The ordinary methods have one-against-rest, one-against-one and DAGSVM, etc. In this paper, we use one-against-one algorithm for face recognition.

5.4 Experiments and Results

Table 10 shows the results of the 9/9 experiment. In 9/9 experiment, the support vector machine misclassified 24 videos only, the recognition rate is 96.78 percent; in 7/11 experiment, the support vector machine misclassified 93 videos, the recognition rate is 94.6 percent.

Table 10 Comparison Recognition Rates.

Kernel function	RBF		Polynomial		Linear	
Random testing number	*9/9*	*7/11*	*9/9*	*7/11*	*9/9*	*7/11*
1	92.8	95.4	95.3	95.7	96.8	96.3
2	97.3	93.9	96.4	97.9	97.0	94.6
3	95.6	93.1	95.8	95.6	96.5	95.0
4	97.6	98.6	96.3	94.8	98.7	94.3
5	96.5	93.6	95.8	96.6	97.0	94.5
6	97.8	96.7	96.2	94.4	98.5	97.8
7	98.5	95.7	94.4	95.6	96.5	96.3
8	96.8	92.8	95.2	96.4	97.0	96.9
9	95.4	92.8	94.3	95.5	95.4	93.7
10	96.8	94.7	94.8	96.8	97.0	94.9
11	97.3	96.7	96.3	96.3	98.0	95.6
12	95.9	93.2	95.4	97.6	97.4	94.5
13	97.3	94.0	97.4	96.5	98.0	96.9
14	96.9	96.3	94.3	95.0	96.0	98.4
15	97.2	93.4	96.8	97.0	94.0.	96.4
16	97.8	91.4	97.7	96.5	98.0	93.2
17	95.6	96.8	95.8	96.0	96.0	97.8
18	97.6	92.2	94.6	96.8	94.2	95.3
19	96.7	94.5	96.8	95.0	97.4	95.8
20	95.8	94.5	93.7	96.0	96.6	94.3
Average	96.78	95.61	94.8	95.13	95.57	94.93

Table 11 shows the recognition rate results of the proposed method for RBF kernel function and other methods. The performance is better than the references [36], [37] and [38]. The experimental results demonstrate the effectiveness of the proposed algorithm in this paper. The above experiments were performed using Emgu CV and C# running on Intel (R) Core (TM) i7 CPU, 2.80 Ghz. Table I shows the classification experimental results of two groups. The classification results obtained by three kernel functions are almost same with better recognition rates as shown in Table 11.

In 9/9 experiment the average classification recognition rate of three kernel functions is 96.57 percent; in 7/11 experiment the average classification recognition rate of three kernel functions is 95.65 percent. Reference [36] extracted the facial features using PCA and classified by SVM, the recognition rate is 95.15 percent. And in reference[37] were used for the Gabor + PCA + SVM and Gabor + KPCA + SVM methods respectively, obtained 93.1 percent and 94.5 percent recognition rates. The

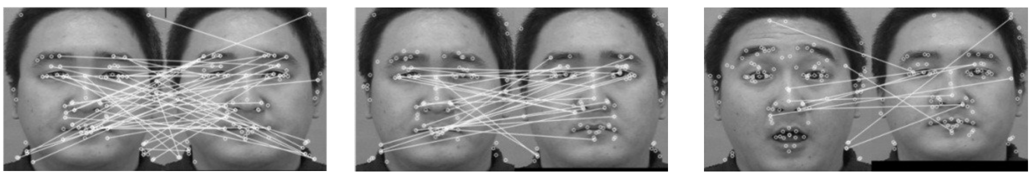
Table 11 Comparison Experimental Results.

Methods	Recognition Rate
Wavelet+SVM [proposed method]	96.78%
Gabor+SVM [36]	95.15%
Gabor+KPCA+SVM [37]	94.50%
Gabor+PCA+SVM [37]	93.10%
Gabor+rank correlation [38]	91.50%

proposed method based on RBF kernel function achieved a recognition rate of 96.78 percent.

A highly accurate and superior face recognition system based on the wavelet decomposition and SVM technique has been proposed. An improved AdaBoost algorithm is adopted to detect the face region and reduce the complexity of human face. The facial features are obtained by wavelet decomposition, which are less sensitive to the facial expression variations. SVM is used to classify the human faces.

Extensive experiment shows the validity of the present system in terms of the parameter at the starting frame shown as Fig.29. SURF is based on sums of 2D Haar wavelet responses and makes an efficient use of integral images.



Frame = 5 Frame = 15 Frame = 25

Fig. 29 The Face Detecting and Tracking using SURF Method. (In this system, capture the video from the second frame, nearer to the second frame, the more feature points lines)

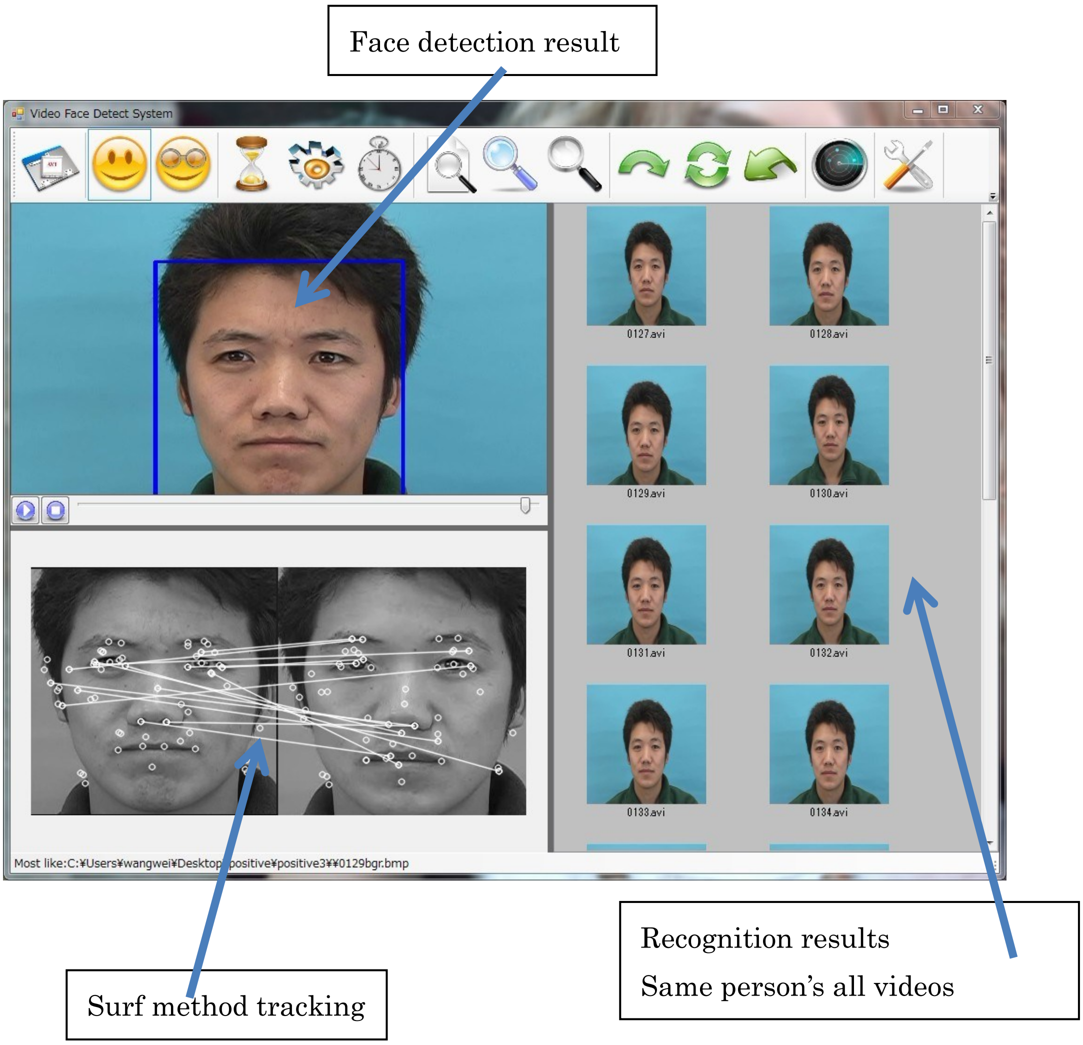


Fig. 30 Automatic Frontal Face Recognition System interface.

CHAPTER VI

CONCLUSIONS AND FUTURE WORK

6.1 Conclusions

In this paper we have presented an extensive survey of machine recognition of human faces and a brief review of related studies. We have considered two face recognition tasks: one is facial feature extraction and the other is classification. In addition to a detailed review of representative work, we have provided summaries of current developments and challenging issues. We have categorized proposed methods of solving these problems and discussed the pros and cons of these methods. Finally, the main contribution of this thesis includes:

(1) A novel fast fractal image compression

A novel fast fractal image coding algorithm based on texture feature is proposed. The most fractal image encoding time is spent on determining the approximate D-block from a large D-blocks library by using the global searching method. Clustering the D-blocks library is an effective method to reduce the encoding time. First, all the D-blocks are clustered into several parts based on the new texture feature alpha derived from variation function; second, for each R-block, the approximate D-blocks are searched for in the same part. In the search process, we import control parameter δ, this step avoids losing the most approximate D-block for each R-block. Finally, the R-blocks whose least errors are larger than the threshold given in advance are coded by the quad tree method. The experimental results show that the proposed algorithm can be over 6 times faster compared to the moment-feature-based fractal image algorithm; in addition, proposed algorithm also improves the quality of the decoded image as well increases the PSNR's average value by 2 dB.

(2) Provided a thorough survey of the AFR history

The latest AFR survey was published in the year 2000, which in fact surveyed the AFR researches before 1999. This thesis has provided a more recent overview of the AFR research and development. Then, AFR methods are further categorized according to facial feature extraction, face representation, and classification separately. We also survey the main public face databases and performance evaluations protocols, based on which the state-of-the-arts of AFR are summarized. Finally, the challenges and technical trends in AFR fields are discussed.

(3) Proposed an eye location algorithm based on HSV color space and template matching

The quality of feature extraction will directly affect recognition results. Eyes are the one of the most important organs of a face including a lot of useful features. Therefore, eye location has become one of the most significant techniques in pattern recognition.

This thesis proposed an eye location method based on the HSV color space model using template matching. At first, we describe an implementation for skin detection which relies on the H channel to characterize the skin colors range, and determine the possible face region. Then we manually extract an average eye template using the human eye's sample images, and finally in the face region, locate the eyes using this average template. As eye template matching, the rectangular region of the eye which confirmed from the skin region is just searched. Compared to other template matching methods that search for the human eye in whole face region, the proposed method saves on the matching time by avoiding the impact of the mouth and nose in the process of positioning. Undoubtedly, this method enhances the accuracy of eye detection.

(4) Investigated the face detection methods, and proposed an improved training AdaBoost algorithm for face detection

Face detection technology as an important part of face recognition has high research and application value. In 2001 the AdaBoost algorithm was applied to face detection by Paul Viola and Michael Jones.

In this section, an improved training algorithm for AdaBoost is proposed to bring down the complexity of human face detection. Two methods are adopted to accelerate the training: (1) A method to solve the parameters of a single weaker classifier is proposed, making the training speed is higher than probability method; (2) a double threshold decision for a single weaker classifier is introduced, and the number of weaker classifiers in the AdaBoost system is reduced. Based on the simplified detector, both the training time and the detecting time could be reduced.

(5) Primarily studied wavelet transform based feature extraction and Support vector machines to face recognition problem; recognition rate is analyzed and evaluated experimentally

The extracted features from human images by wavelet decomposition are less sensitive to facial expression variation. As a classifier, SVM provides high generation performance without transcendental knowledge. First, we detect the face region using an improved AdaBoost algorithm. Second, we extract the appropriate features of the face by wavelet decomposition, and compose the face feature vectors as input to SVM. Third, we train the SVM model by the face feature vectors, and then use the trained SVM model to classify the human face. In the training process, three different kernel functions are adopted: Radial basis function, Polynomial and Linear kernel function. Finally, we present a face recognition system that can achieve high recognition precision and fast recognition speed in practice. Experimental results indicate that the proposed method can achieve recognition precision of 96.78 percent based on 96 persons in Ren-FEdb database that is higher than other approaches.

6.2 Future Work

Face recognition is a challenging problem in the field of image analysis and computer vision that has received a great deal of attention over the last few years because of its many applications in various domains. Research has been conducted vigorously in this area for the past four decades or so, and though huge progress has been made, encouraging results have been obtained and current face recognition systems have reached a certain degree of maturity when operating under constrained conditions; however, they are far from achieving the ideal of being able to perform adequately in all the various situations that are commonly encountered by applications utilizing these techniques in practical life. The ultimate goal of researchers in this area is to enable computers to emulate the human vision system and, as has been aptly pointed out by Torres [34], “Strong and coordinated effort between the computer vision, signal processing, and psychophysics and neurosciences communities is needed” to attain this objective.

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