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Applications and Mathematics Methods used in Software Engineering for Techniques Facial Recognition

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Abstract: Facial recognition involves detecting a person and identifying their face. The tasks of searching and identification are not simple and depend heavily on the computational power of the platform used. Similar to the human eye's capability to detect and recognize a face within its range, computer systems require working with low-contrast images and applying various filters to minimize noise and interference. This process transforms images from low contrast to higher resolution, creating different feature vectors and matrices, and establishing various facial criteria for each stage of the system. The recognition of an individual through their face is precisely tuned by a comprehensive set of algorithms that operate based on mathematical theories and methods used in electronic systems to detect and identify human faces.

Keywords: Mathematics methods, facial recognition, software engineering, biometric information systems ، processing stage.

Introduction

The need to identify individuals is growing annually and is gaining more attention in the modern information world. In security matters, both digital data and physical components have never been more crucial. Since the beginning of the twenty-first century, there has been rapid development in solutions for personal digital information and property security problems: from passwords on websites and electronic combination locks on doors to fingerprint recognition and retinal scanning on phones. Despite these advancements, the ideal method for identifying an individual is through facial recognition, as the human face is one of the most distinctive personal identifiers. Facial recognition is a key task in solving security problems, offering remarkable advantages in the modern world. Considering the development of intelligent systems and the continuous improvement of security systems, we can conclude that these systems are not only used in specially protected areas but also in various civil infrastructure facilities, including but not limited to:

1. The facial recognition system developed at Tsinghua University in Beijing, which has been adopted by the Chinese Ministry of Public Security for use in public places.
2. Omron's Japanese branch, specializing in recognition, automation, and control technologies, developed the Riya facial recognition system for mobile phones.
3. A group of specialists in facial recognition algorithms at Stanford University established a web service for contextual searching of facial images within digital photo albums.

4. A4Vision announced that the Federal Security Service, along with the U.S. Department of Homeland Security, has implemented 3D facial recognition biometrics at the Tenth District Center.

The purpose of this work is to develop an automated access system in buildings using facial recognition. To practically implement such a system, the following tasks were identified:

a) Develop the control circuit components, i.e., an electromechanical lock.

b) Develop a software list that allows for system software changes (e.g., entering data of individuals) without dismantling the structures.

c) Develop and implement software for real-time facial identification from the video stream of the camera unit.

1. Phases of Facial Recognition System Operation

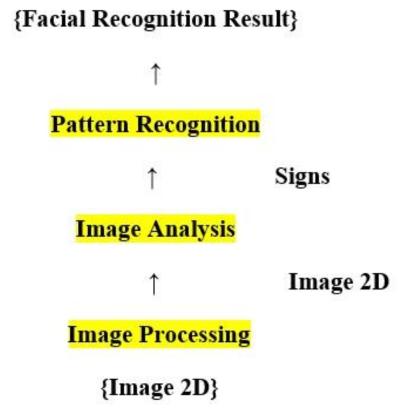

Figure (1-1) The stages of facial recognition system operation are illustrated.

1.1 Image Processing Stage

Various image processing procedures are applied so that it becomes possible to work with the images without any conventions or complexities in order to "train" the system to recognize faces. This processing is done to prepare the image for the next stage, which is image analysis.

The standard procedures used in the image processing stage include:

a) Removal of impurities and noise.

b) Contrast enhancement.

c) Image sharpening.

d) Rotation and perspective leveling of the image.

1.2 Image Analysis Stage

In this stage, the image is analyzed and information is extracted from the image, or more precisely, the distinctive components and their meanings are transferred. This stage allows us to analyze images obtained from various types of cameras, whether black and white, colored, or even infrared cameras. These images are not neglected but are processed by more commonly used algorithms from images that have been previously converted to gray scale. This is done to utilize the system platform's production capacity more realistically, enabling the facial recognition algorithm to function effectively. The processing of monochrome images differs significantly from that of colored images in terms of time12.

1.3 Pattern Recognition Stage

This stage involves comparing the classifications of feature vectors obtained from the image analysis stage with the features acquired at a specific moment, such as images obtained from a video camera stream or images that have entered the system in some other manner. Regardless of how the images are obtained, the current images are characterized by the absence of preprocessing, unlike the images that underwent the image analysis stage. The information outputs from this stage may vary, depending on the applied pattern recognition method. It is essential to note the factors that arise during facial recognition and lead to variations and interference in the recognition process:

a) Partially covered face;

b) Head movement and rotation in different directions;

c) Variations in lighting intensity and angles;

d) Facial expressions.

2. Methods of Facial Recognition

In this section of the research, each method of facial recognition is analyzed, detailing the mathematical approaches and techniques used. All these techniques rely on facial geometry and the established fact that the set of facial features and the proportions and shape of each person's skull are unique. Based on this, we can highlight the main stages of facial recognition, which are presented above.

2.1 Viola-Jones Method

The Viola-Jones method was first described in 2001 by Paul Viola and Michael Jones. This method enables fully automatic facial recognition. Compared to other methods, Viola-Jones has advantages such as lower algorithm complexity and reduced system resource requirements, making it possible to apply this method in real-time. The main approach involves using Haar features, i.e., performing image analysis based on distinctive facial features inherent in everyone. Therefore, factors like skin color or ethnicity, as well as lighting, do not affect the method's results. The authors of the method proposed using integral representation (image - matrix) that matches in size with the original matrix, where each element stores the sum of all elements to the left and above the selected element [13]. The elements are presented in matrix form and are calculated according to the following formula:

$$I(x,y) = \sum x` < xi\ (x`, y`)$$

$$y` < y$$

Where $i(x', y')$ is the pixel brightness of the original image, each element $I(x, y)$ of the integral image contains the sum of pixel intensities within the selected rectangle from (0, 0) to (x', y'). The formation of the integral image takes linear time proportional to the number of pixels in the original image and can be computed in a single pass to calculate the integral image. It can be performed according to the following formula:

$I(x, y) = i(x, y) + I(x - 1, y) + I(x, y - 1) - I(x - 1, y - 1)$

The most important advantage of representing the integral image is the ability to calculate the sum of pixels forcibly and quickly for any rectangle or any other shape that can be approximated to several rectangles. These rectangles are drawn and outlined according to the following formula:

$S = \sum_{x_0 \leq x \leq x_i} \sum_{y_0 \leq y \leq y_i} i(x,y) = I(A) + I(C) - I(B) - I(D)$

To describe the desired objects or groups and to distinguish them, a "haar cascade" is a set of objects of shape (2-2) that wrap around the image. In this case, the simplest objects are used, which have only two levels: -1 and +1. Each rectangle is used multiple times but with different sizes. The letter S refers to them according to the following formula:

$$s = X - Y$$

Where:

- \(X \) is the sum of elements of the image in the light area.

- \(Y \) is the sum of elements of the image in the dark area.

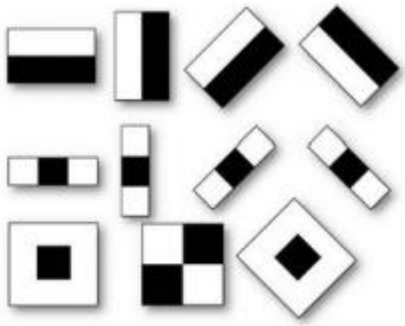

Figure (2-1) Haar Features

Haar Features: Haar features were introduced by Viola and Jones. They were named as such due to their resemblance to Haar wavelets, which are one-dimensional convolutions representing the difference between the nearest two samples, indicating the twisting function. As illustrated in the following figure.

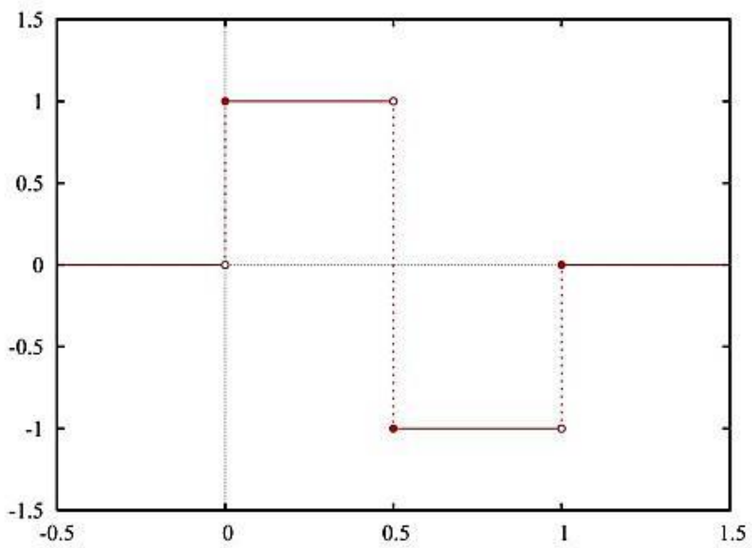

Figure (2-2) Haar Wavelets

Haar Wavelets: A Haar feature is a rectangular area divided into two adjacent regions. Features are imposed on the image at different positions and scales. The value of the feature is defined as the difference in the sum of pixels from the regions. As shown in the previous figure (2-2), examples of Haar features are provided. Each feature is responsible for a specific property of the image. For example, the presence or absence of two adjacent regions can indicate boundaries between light and dark areas in the image. The feature area can be larger and expanded by using diagonal features through diagonal marks. Additionally, the presence of an edge at a certain angle can be determined. However, real-time image acquisition usually involves low-resolution images, which may cause approximation issues when using diagonal features. Despite this, the idea behind these features is mathematically sound. In general, using Haar features is one of the primitive methods for face detection, as shown in the following figure.

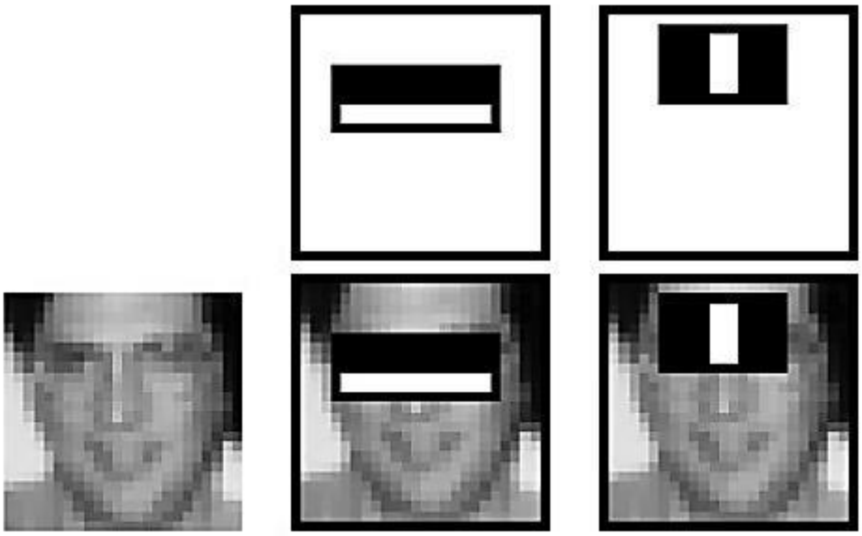

Figure (2-3) Primitive Haar Features

2.2 Local Binary Pattern (LBP) Algorithm:

In 1996, Timo Ojala and Matti Pietikäinen described the algorithm for the first time, adopting "templates" - a description of pixel neighborhoods in the image in binary form, assuming that the central pixel is the threshold. The algorithm uses 8 pixels located near the central point, meaning that the value "1" is assigned to those pixels with a value greater than or equal to (≥) the central pixel. The value "0" is assigned to those pixels with a value less than (<) the central point. Thus, the state of each pixel is described by a binary code consisting of 8 triangles. Examples of running the LBP algorithm include:

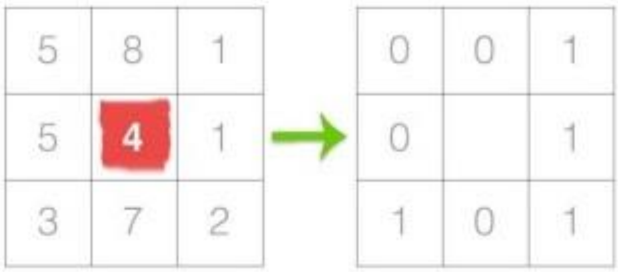

Figure (2-4) Illustration of an Example of LBP Algorithm

This figure demonstrates an example of the Local Binary Pattern (LBP) algorithm. Based on the obtained numbers for all the divided parts to transform the image into a graphical representation, completing all the parts constitutes a carrier, allowing the presentation of information and image features in determining similarity between two individuals. The vector for each part of the image is calculated and compared.

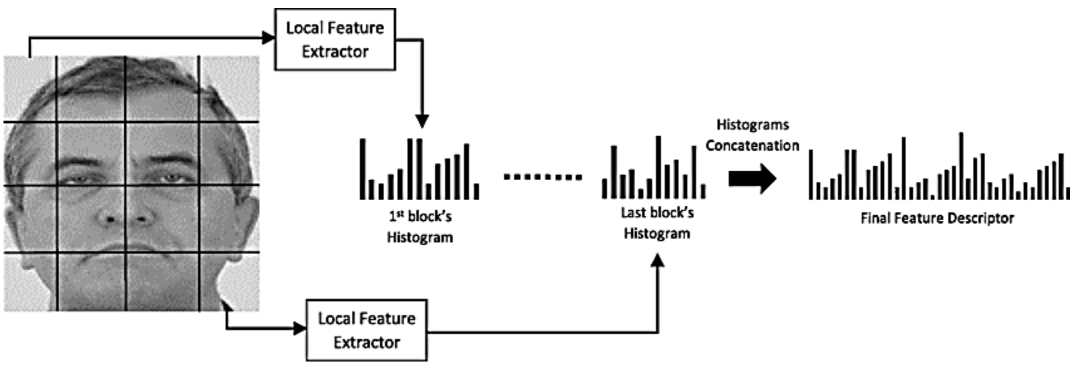

Figure (2-5) Example of Creating and Graphing the Entire Image

Among all the methods mentioned above, only the Viola-Jones method is capable of achieving real-time processing directly from video cameras. Other methods require a longer time for image processing. The developed system uses two methods for image processing for recognition purposes:

1. The Viola-Jones method as described above and the Local Binary Pattern (LBP) algorithm.
2. Local Binary Pattern (LBP) algorithm.

Conclusion

Throughout this study, theories and mathematical methods for personal identity verification were explored, alongside existing solutions in the field of facial recognition using computer vision techniques, in line with our objectives. Tasks included representing control circuits for the motor (electromechanical lock), designing and assembling circuit boards for devices, and working on revising the operator to allow changes to the system software without dismantling equipment. Software developed and experimentally tested for real-time facial recognition systems, where images are fed into the system via video cameras. Experimental studies revealed that the developed system can identify a person's face with an accuracy of up to 90% when using the specified features. These advancements were achieved even on modest controller platforms with low power, small memory capacity, and low performance. However, image processing from the camera unit causes time delays. Execution on more advanced controller platforms significantly improves facial recognition performance, even in low-light conditions. It is possible to connect a video camera with infrared lighting to the system, further enhancing results. The platform used plays a crucial role in improving system performance by increasing platform capabilities, controlling units, and processing data efficiently.

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