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A Review of Face Detection Methods Based on Feature Approach

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Abstract— *Face detection technology is the first and essential step for facial-based analysis algorithms such as face recognition, face feature extraction, face alignment, face enhancement, and face parsing. That is besides serving other applications related to human intention and act analysis such as facial expression recognition, gender recognition, and age classification. Face detection is used to detect faces in digital images. It is a special case of object detection and can be used in many areas such as biometrics, security, law enforcement, entertainment, and personal safety. There are various methods proposed in the field of face detection, and they all compete to make it more advanced and accurate. These methods belong to two main approaches; feature-based approach and image-based approach. This paper reviews the face detection methods that belong to the feature-based approach. Moreover, their work concepts, strengths, and limitations are mentioned. This paper concentrates on the feature-based approach due to its simplicity and high applicability in real-time detection compared to the image-based approach.*

Index Terms— *Face Detection Methods, Feature-Based Approach, Viola-Jones Algorithm, Deformable Template Matching.*

I. INTRODUCTION

Face detection is defined as finding a human face within an image or video and determining the location and size of that face [1][2]. The main purpose of using several face detection methods is to overcome challenges and enhance performance. This includes, for example, reducing detection and training time, and increasing detection accuracy. Face detection is used in numerous applications such as face enhancement [3], gender recognition, human-computer interaction system, biometric attendance, face identification [4], face verification, face recognition [5][6], face alignment [7], face feature extraction [8][9][10]. Face detection is a challenging task for computer vision because of the diversity of face conditions within images such as size, shape, color, direction, expression, lightning, and face occlusion by other objects such as other faces, beards, and glasses [6][11]. Other possible challenges are image noise, illumination, and occlusion [2]. In the latest views, face detection methods are categorized into two main approaches and not four as older views suggest. These two are feature-based and image-based approaches. This paper concentrates on feature based approach and its methods. Face detection performance is evaluated by various metrics such as, time consumed for training and detection, the samples amount in the training dataset, and the ratio between the detection rate and the false alarm.

Several face detection surveys have been done and some are reviewed here. In 2010, C. Zhang et. al. [1] introduced a survey on the various learning algorithms and feature extraction techniques used for detecting faces since the Yang et. al. survey in 2002 [12]. Zhang et. al. put face detection methods into four approaches, knowledge-based, feature invariant, template matching, and appearance-based approach. Their paper reviewed in detail the feature types used in face detection methods starting from simple features such as Haar-like features to the more complex features such as generic linear features. Moreover, they discussed each type's variations, strengths, and limitations. They mentioned the viola jones method used for face detection (as it was the pioneer in real-time face detection) and they

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concluded that Haar-like features used in viola jones are simple and efficient for only detecting frontal face, but using more complex features in the form of a post filter can also be efficient and will significantly enhance the performance of the detector. Regarding the learning algorithms used in face detection, they indicated that the boosting learning algorithm is a great choice if all features are predefined, and that other learning algorithms such as SVM or CNN can perform fairly with built-in mechanisms for new feature generation. In 2014, a study and analysis of different face detection methods is made by M. Chauhan et. al. [13]. The study considered the methods of face detection based on the main four approaches. The authors' main goal was to come up with a good candidate approach. They focused on face detection for authentication and identification purposes. They found from theoretical analysis and comparison and focusing on the key parameters that, the face detection method based on Haar-like feature extraction is a very good candidate for face detection. In 2015, Hatim et. al. [14] conducted a survey on the methods belonging to the feature-based approach due to its great results on human face detection. The methods are analyzed and discussed and their performance is compared by indicating the advantages and disadvantages. The paper gave a summary of the databases used for face detection including the number of images, size of the image, and face poses in each database. The authors concluded that each method has its own merits and demerits. In their survey in 2018 on feature-based face detection methods, A. Albakri et. al. [15] concluded that gray-based analysis, motion-based analysis, and Viola Jones algorithm achieved the best results among the different techniques they explored. In 2019, A. Kumar et.al. [2] reviewed face detection techniques with their advantages and disadvantages. The study was based on two main approaches, feature and image-based approaches, with a comparative study on them. However, the work focused on feature-based approach methods. They also mentioned various standard databases used for face detection with their properties and the available facial recognition APIs. In 2021, K. Hasan et.al. [16] proposed a wide variety of face detecting methods that belong to both feature and image based approaches. The study included method history, working procedure, strengths, limitations, and the fields of use. Also, it provided a brief comparison among algorithms in each method. In 2022, A. N. Razzaq et.al. [17] reviewed various face detection algorithms and indicated their different applications and challenges. The paper provided some information about the standard face detection databases with their environmental conditions, such as illumination, occlusion, expressions, and head poses. Furthermore, it provided special discussions regarding highly practical aspects for the robustness of the system for face detection.

II. FACE DETECTION APPROACHES

Many face detection methods that belong to one or more approaches have been developed. The main goal of these methods is to define the face location within the image or video frame. Researchers' continuous improvement and development for the performance aim to enhance the detection accuracy and reduce the time consumed in detection and training processes. Recent researches categorize face detection approaches into only two main approaches: feature-based approach and image-based approach [7][8][1]. This paper concentrates on the feature-based approach and its methods.

III. FEATURE-BASED APPROACH

This approach is based on extracting face features from the image and matching it against the facial features knowledge database [17][18][15][8]. Facial features could be skin-color, eyes, eyebrows, nose, lips, and hairline [18]. A statistical model is built based on the extracted face features to describe their relationships and to define the face's existence [11]. Feature-based approaches are further divided into three methods: low-level analysis, active shape model, and feature analysis. Feature analysis was first introduced in 1946 (Gabor feature), while LLA was introduced later in 1972 (edge-based), and lastly, ASM was introduced in 1988 (snakes). *Fig. 1* shows the feature-based methods since 2001.

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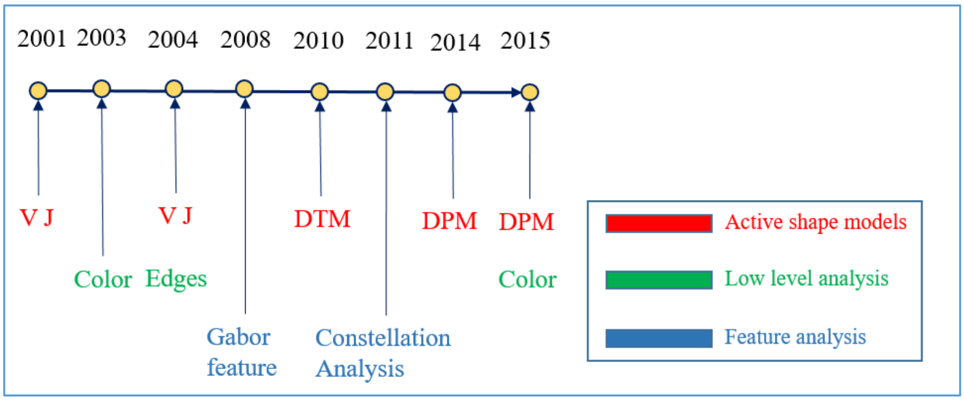

FIG. 1. FEATURE-BASED DIVISIONS AND SUB-DIVISIONS FOR FACE DETECTION SINCE 2001.

A. Low-Level Analysis (LLA)

This method is used to analyze the basic components in the image (like intensity, color information, edge, texture, and motion) for detecting a face [15]. For example, if an image contains a face, the LLA descriptors will define the edges' locations in that face, the different color variations of the image and face…etc. Provided that the descriptors are associated with an image, the LLA descriptors are not only applied to the face region but also to the whole image. This method can be further divided into four categories: motion-based, skin color-based, gray information, and edges. All sub-categories are considered to be fast, and some of them such as, grey and edge-based, are highly sensitive to images with a noisy background. LLA divisions are different from each other in the point of reference.

Skin Color Based is one of the LLA methods. Human skin color can be considered a feature and it could mainly distinguish human faces from other objects within the image. Skin color-based face detector was popularly used in 2003. There are several color faces detection models, such as RGB (red, green, and blue) model, YIQ (luminance, in-phase, quadrature) model, and the HIS (hue, intensity, saturation) model [16]. In the RGB model, different colors are defined by combining the primary color components (red, green, and blue). The pixel values corresponding to a face are extracted to detect a face shape. While HIS model shows the highest performance compared to other color models in obtaining a large variance among color clusters of face features. Therefore, this model is used for extracting facial features like eyes, lips, and eyebrows. Furthermore, it is used in face segmentation schemes because the representation is highly related to the human perception of color. And lastly, the YIQ model works by boosting RGB colors for YIQ representation. This conversion shows the contradiction between the face and the background, and this in turn, enables detecting the face in a natural environment [19]. The skin color model is used by one of the works to segment the image and extract skin regions and then detect faces within the image [15][11]. In another work [20] applied some noise removable types then created a skin map, and search for two eyes within each detected skin color region, if the eyes are founded then the face is detected. Otherwise, no face is detected. Just like skin color, skin also has a texture feature that can be employed to distinguish between the face region and the background. A face detection algorithm could combine skin color features with other features like edge, as one of the works suggested and introduced, to increase efficiency and decrease the false acceptance rate. This algorithm reduced false acceptance to (21), while it was (128) in the case of using the skin texture feature only.

In 2022, many types of research have been done that used skin color methods such as; *R. Satheeskumar* [21] which proposed a face detector using L.A.B. color transformation and a binary segmentation for skin and non-skin analysis. The experimental results of the proposed method show invariably the lighting variations under which the image was taken. Moreover, the results validated the method's robustness and efficiency in different poses and expressions. While S**.** *Ittahir et. al.* [22],

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used a skin color face detector to estimate the number and location of people's faces in images. The algorithm tested (133) images from the people image group dataset. And the best precision achieved was 85% based on the obtained results. Moreover, *M. Alhameed et. al.* [23] explores the identification of the human face and eye in frontal color images. The proposed algorithm achieved around 94% accuracy and was able to find face locations in single-face images. Table I shows the strengths and limitations of the skin color-based method.

TABLE I. STRENGTHS AND LIMITATIONS OF THE SKIN COLOR-BASED METHOD

No.	Strengths	Limitations
1	Processing skin-color feature is much faster than processing other facial features [2].	Errors may occur in detecting non-face objects of similar color to faces [24].
2	This method is scale-independent and rotation independent.	Sensitivity to illumination variation and the different types of cameras could cause different color values.
3	The detection does not depend on facial features. Thus, faces can be detected even in difficult expressions, or in side-view direction [25].	Low accuracy occurred when detecting side-viewed faces.

B. Active Shape Model (ASM)

It is a point-distributed model that creates a face shape to use in face detection within images. The face landmarks are represented by these points which may vary in a location with some tolerance. ASM method is further divided into four divisions: snakes, deformable template matching, deformable part model, and point distribution model. All ASM divisions use deformation and require an initialization point. However, they are different in their deformation technique.

Deformable Template Matching (DTM) is one of the ASM methods. In 1992, YUILLE et.al. [26] proposed deformable templates to detect and describe features of faces. Template matching is a set of techniques that search for highly similar patches between images and a template image [27]. Deformation is based on narrow valley, edge, peak, and brightness. To describe a feature in the face (such as an eye) by using a parameterized template, an energy function is formed to link features like peaks and edges in the image intensity to the corresponding template features. Then, the template interacts dynamically with the image by changing the values of its parameters to reduce the energy function, in that way the template is deformed to find the best fit. The final values of the parameter can be used as feature descriptors [2]. DTM creates face-deformable shapes by using pre-defined shapes. These pre-defined shapes can be created either by polygonal templates or by hierarchical templates (HTs). In the polygonal templates, as shown in *Fig. 2*, a face is created using several triangles, where each triangle is deformed to contort the overall shape of the face.

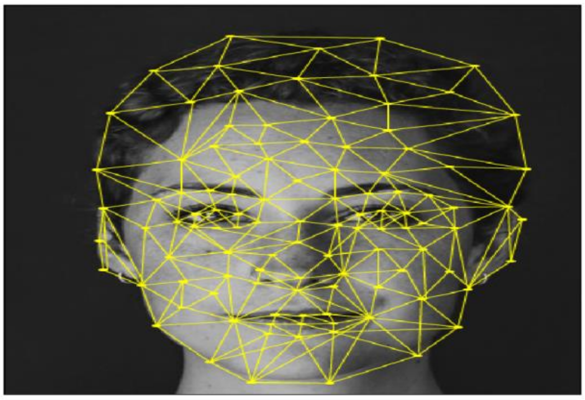

FIG. 2. POLYGON TEMPLATE OF THE FACE IS MADE UP OF TRIANGLES [2].

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Another type of DTM creates a tree shape as shown in *Fig. 3* [16]. This type does not recommend the training step. Instead, the deformation is obtained by pre-defining a set of basic rules. for example, the right patch cannot pass across the left patch [27].

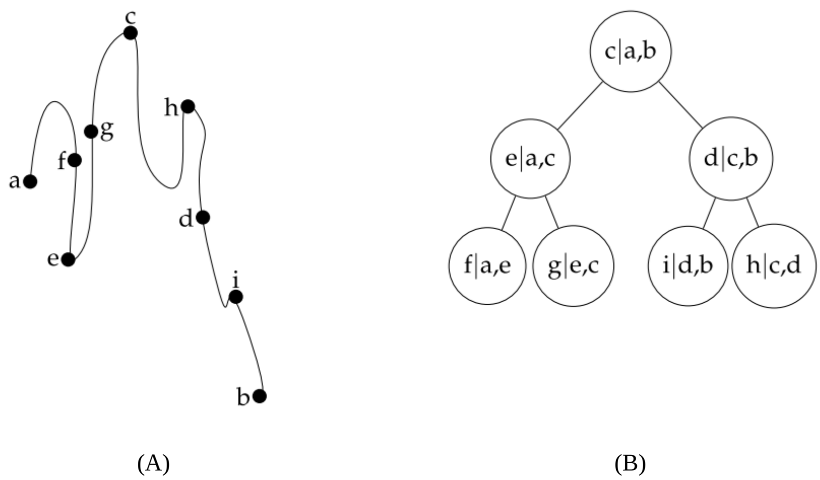

FIG. 3. DEFORMATION OF BINARY SHAPE TREE IN BUILDING HT. (A) THE DISTANCE FROM POINT 'A' TO 'B' ARE MARKED. (B) THE RESULTING HIERARCHICAL TREE [2].

In 2020, a combination of unlabeled data learning with semi-supervised learning have been done by Han T. et. al. [28], which enhance the performance of the classification process with few labeled data and reduce the cost of data annotating. This work achieved top performance after several experiments and analyses were done on four standard SSL benchmarks (for example it achieved 90.46% accuracy when using CIFAR-10 with 40 labels and achieved 95.20% accuracy using 250 labels). In the same year, Daga, A. et. al. [29] produced an offline motion-tracking of the fan, and obtain a reliable estimate of the IAS (Instantaneous Angular Speed). The proposed algorithm is an update of the established template matching, which is here integrated into a genetic algorithm search. Table II shows the strengths and limitations of the DTM method.

TABLE II. STRENGTHS AND LIMITATIONS OF THE DTM METHOD

No.	Strengths	Limitations
1	DTM provides better extraction by combining local information with global information.	It requires excessive processing time due to the execution of the sequence of minimization processes.
2	DTM doesn't require the training step. And it is adaptable to any shape type in the given data.	Sensitivity to the initializing position. for example, in Fig .3, the midpoint 'c' is required to be initialized in HTs.
3	Ability to work in real-time.	

C. Feature Analysis (FA)

The feature analysis algorithms aim to find structural features which exist even in variant poses, viewpoints, or illumination, and then use features to find face location. These algorithms are mainly designed to locate the face. The feature analysis is based both on a prior face model and on the proportions of normalized distances and angles derived from the individual description of face landmarks such as (lips and eyes). This method is divided further into the feature-searching method and

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the constellation method. The first method is to define facial features by the relative position of these features, and the other method uses flexible face structures. Both methods are working well on cluttered backgrounds, but face challenges in getting features positioned correctly [16]. All feature analysis methods face difficulties in locating features correctly. Moreover, they work well on cluttered backgrounds. However, they are different in the reference they used. For example, the feature search method uses head, mouth, ears, and eyes as references. While references used by the constellation analysis method are eyeballs and the distance between eyes.

Viola-Jones Algorithm is one of the feature analysis methods. It was introduced in 2001 by Paul Viola and Michael Jones [30]. This method has very important impact on face detection research during the past two decades. It is widely used in several applications such as digital cameras, and in software used for managing digital photos. Viola-Jones was the first face detection method that achieves real-time. It is capable of processing images rapidly and high detection rates [31]. It is first proposed to detect a human face. However, it is able to detect any other object. It mainly consists of four parts: Haar-like features, integral image, Adaboost, and cascade classifier, as shown in *Fig. 4*.

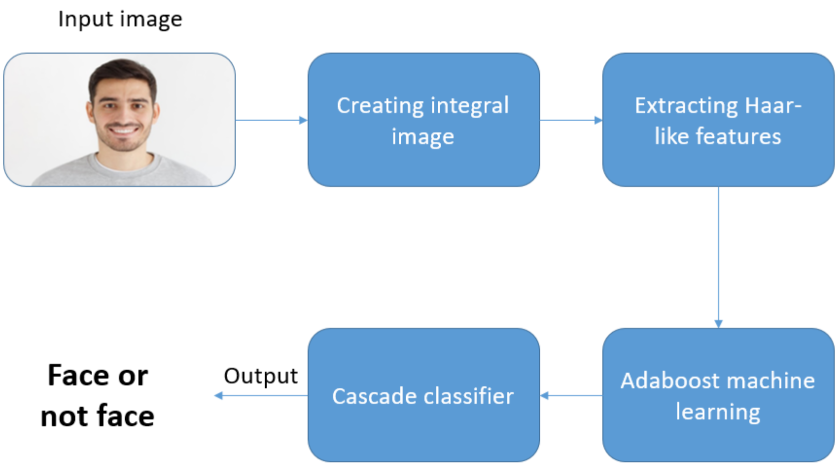

FIG. 4. FACE DETECTION BY VIOLA-JONES.

a) Haar-like Features

Viola-Jones algorithm extracts these features for detecting face features like (edges or lines) [30]. Haar-like features are the difference between the sums of pixel intensities in adjacent rectangular regions at a specific location in the detection window. Viola-Jones uses three types of Haar-like features; two-rectangle features, three-rectangle features, and four-rectangle features.

b) Integral Image

This is also called summed area table. It is introduced by Viola and Jones to rapidly determine Haar-like features in different sizes. The summed area table is computed in one pass over the image and by only a few operations per pixel [30]. Each pixel in the integral image is determined by finding the cumulative sum of the corresponding pixel in the input image with all pixels above and to the left of it [31].

c) Adaboost Learning Algorithm

In viola-jones, the Adaboost learning algorithm, short for Adaptive Boosting, is used for selecting the features and training the classifier [30]. Adaboost learning algorithm selects only a small set of the important features (weak classifiers) from a larger set of features and yields an extremely efficient classifier (strong classifier).

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d) Cascade Classifier

It combines increasingly more complex classifiers in a cascaded way, which enables background regions of the image to be quickly discarded while spending more computation on regions like the face [30].

In 2019, *Tejas R.* et. al. [32] build their own custom haar cascade classifier using a tool for detecting a face in any given image. This tool is designed by Amin Ahmadi and is called (Cascade Trainer GUI). The authors also create a dataset used for training and contain both positive and negative samples. Later in 2022, Sulaiman M. et. al. [33] proposed a systematic review of the evaluation of monitoring systems for driver fatigue based on the existing algorithm for detecting face /eyes. This work dealt with 74 eye and face detection studies and an algorithm comparison that was used in previous research. They validate that the Viola-jones algorithm is the best face detection algorithm regarding the accuracy, which was up to 98%, for different databases of faces. Moreover, the Viola-Jones algorithm depends on face geometry and it is capable of detecting all faces contained in one image.

In 2020, Vinh T. et. al. [34] proposed a real-time face mask detector using both YOLOv3 and Haar cascade classifier (Viola-Jones) algorithms that has strength and limit points, shown in Table III. The application was to check if people wearing a mask or not. The achieved accuracy was up to 90.1%. They used the MAFA dataset. The system is able to work in real-time with 30 fps.

TABLE III. STRENGTHS AND LIMITATIONS OF THE VIOLA-JONES METHOD

No.	Strengths	Limitations
1	Capable of processing images extremely rapidly and achieving high detection rates, it is used in real-time.	It can only detect frontal faces.
2	Low false positive rate.	Intensely large training time.

A comparison between deformable template matching, skin color-based, and Viola-Jones methods is shown in Table IV.

TABLE IV. COMPARISON BETWEEN DTM, SKIN COLOR, AND VIOLA-JONES METHODS

	DTM	Skin-color	Viola-Jones
Method	Active shape model.	Low-level analysis.	Features analysis.
Technique	Work by forming deformable shapes of the face.	Works by building a skin color classifier. Which is used to label the pixel as either skin or non-skin pixels.	Works through four steps, haar-like features, integral image, Adaboost learning algorithm, and cascade classifier.
Training step	Not required.	Required.	Required
Advantage	Accommodative with any given shape.	Faster than other facial feature processing.	High detection accuracy.
Disadvantage	Sensitivity to the initialized position.	Sensitivity to luminance.	Sensitivity to lighting conditions.
Uses in Other fields	Lane detection, and vehicle segmentation.	Detecting hands.	Can be used for any object detection.
Performance	Good performance.	Better.	Better.

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IV. CONCLUSIONS

The reviewed face detection methods in this paper belong to the feature-based approach. Feature-based approach work is based on searching for facial features. The feature-based approach is divided into; active shape model (ASM), low-level analysis (LLA), and feature analysis (FA). The performance of LLA and FA is better than ASM. Some methods (such as LLA and Feature analysis methods) focus on low-level features such as edges, lines, and color. While other methods (such as ASM) focus on complex non-rigid features like the actual physical and higher-level appearance of features. For example, viola jones (feature analysis-based method) searches for edge and line features, while the skin color-based (LLA-based method) searches for a color feature. Feature-based methods are simple and efficient, scale-independent, rotation independent, and fast. They are better than image-based approaches in real-time detection.

Some methods work better when combined with other methods, such as A method of face detection combined skin color detector and template matching method. The template matching method is used to remove non-faces and to detect faces more accurately.

No particular method is recommended in all cases of face detection because each method has strengths and limitations. Choosing the appropriate method depends on the application and the purpose of use. For example, some applications require fast detection rather than very high accuracy such as social media applications. While other applications require very high accuracy rather than fast detection, such as applications used in the medical field for disease diagnosis. Numerous algorithms have been developed and improved to tackle face detection challenges such as low image resolution, variation in lighting conditions, face occlusion, and unexpected expression. But it is still difficult to detect faces in such conditions. Wherefore, there is plenty of space for innovation. And undoubtedly, the door is still open to ideas that can still improve face detection systems regarding time and accuracy as well as the resources needed.

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