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# Facial Analysis for Real-Time Application: A Review in Visual Cues Detection Techniques

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**Abstract:** Emerging applications in surveillance, the entertainment industry and other human computer interaction applications have motivated the development of real-time facial analysis research covering detection, tracking and recognition. In this paper, the authors present a review of recent facial analysis for real-time applications, by providing an up-to-date review of research efforts in human computing techniques in the visible domain. The main goal is to provide a comprehensive reference source for researchers, regardless of specific research areas, involved in real-time facial analysis. First, the authors undertake a thorough survey and comparison in face detection techniques. In this survey, they discuss some prominent face detection methods presented in the literature. The performance of the techniques is evaluated by using benchmark databases. Subsequently, the authors provide an overview of the state-of-the-art of facial expressions analysis and the importance of psychology inherent in facial expression analysis. During the last decades, facial expressions analysis has slowly evolved into automatic facial expressions analysis due to the popularity of digital media and the maturity of computer vision. Hence, the authors review some existing automatic facial expressions analysis techniques. Finally, the authors provide an exemplar for the development of a facial analysis real-time application and propose a model for facial analysis. This review shows that facial analysis for real-time application involves multi-disciplinary aspects and it is important to take all domains into account when building a reliable system.

**Key words:** Face detection, facial expression analysis, real time facial analysis, visual domain, facial action coding system.

## 1. Introduction

Facial analysis in real-time applications is an emerging technology to provide the highest realism in the entertainment industry and to aid in threat prediction in surveillance. While the games and film industry are trying to create realistic animated faces in the characters, surveillance systems are striving to recognise facial expressions and micro-expressions in real-time profiling. In this paper, the authors elaborate the state-of-the-art of facial analysis techniques in the visual domain. It covers the detection, tracking and recognition in still image and videos.

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Facial information is a type of biometric. The definition of biometric is: a science involving statistical analysis of biological characteristics, or the technologies that analyse human characteristics for automatically recognizing or verifying identity [1]. The measurable physical or behavioural characteristics should satisfy [1]: universality, uniqueness, permanence, collectability, acceptability, performance, and circumvention. Many existing security biometric techniques are not most convenient and are not natural enough for the user. For example, in the case of iris scan technology, the subject is required to comply and pose for the iris scanner. Facial analysis, on the other hand, can offer non-intrusive and perhaps the most natural way of authentication [2]. This is due to the fact that it is intuitive and usually can be non-invasive. Many applications have adapted face recognition. Examples include biometric passports and driving licences, authentications for secure banking and financial transactions and video surveillance. For instance, recently, Cotsaces et al. [3] proposed face-based digital signature in video retrieval.

This paper is presented in eight sections. Section 2 presents the background and the motivation of the project, followed by, in Section 3, a detailed survey of face detection techniques and comparison of face detection techniques. Section 4 reviews the facial expression analysis. Further the authors present the review of automatic facial expressions analysis in Section 5, face tracking methods in Section 6. Section 7 presents the proposed model of this project and finally, the authors conclude this paper in Section 8.

## 2. Background

The motivation for this work arises from a research project funded by UK Engineering Physical Sciences Research Council under the theme of the facial analysis for real-time profiling project (EP/G004137/1). The aim of the project is to provide a real-time dynamic passive profiling technique, which has the potential to improve hit rates at border control points. The project is intended to combine and build on several research areas, which include multi-modality face and eye-movement tracking [4], eye-movement related to intent, dynamic thermal/visible face information related to intent [5], statistical shape [6], appearance modelling [7], face modelling and recognition. In this paper, the authors will concentrate on visual face detection which they hope will form the basis for a real-time algorithm for tracking of both the face and the associated facial features.

The goal of face recognition is to find a similarity measure invariant to illumination changes, head pose and facial expressions so that images of faces can be successfully matched in spite of these variations [8]. Hence, these issues have become the challenges in face detection. The face detection algorithms aim to detect the presence of people in complex images, diversity of variations in the face class such as racial characteristics, facial expressions, hair-style, make-up, glasses, beard, illumination and head pose [8]. The performance of visual face recognition may degrade under poor illumination conditions or for subjects of various skin colours [2]. Some constraints in visual face detection have opened the research for thermal infra-red images in facial analysis [9, 10].

## 3. Face Detection

In real-time applications, the first step of the system is to be able to locate the face. A definition of face detection by Yang et al. [11] is: “Given an arbitrary image, the goal of face detection is to determine whether or not there are any faces in the image and if present, return the image location and extent of each face”. Measurement of accuracy in face detection is “detection rate”, which is defined as the ratio between the number of faces correctly detected by the algorithm and the number of faces determined by a human [11]. There are two types of errors in the measurement of accuracy: false negatives (faces are missed) and false positives (non-faces are categorised as face). In most of the case, a fair evaluation can tune the parameters to obtain good result.

Face detection is not a new research area and it has a long history. Some of the surveys on face detection are done by the following groups:

- Covering work before 1991, Samal and Iyengar [12] did a survey on face recognition techniques.
- In 1995, Chellapa et al. [13] wrote a survey on face recognition and some detection methods;
- In 2002, Yang et al. [11] published a survey paper on detecting faces in images;
- In 2003, Zhao et al. [14] published a survey paper on face recognition;
- In 2005, Kong et al. [2] published a review paper

on visual and infrared face recognition.

Some of the prominent face detection techniques include: neural network-based [15], distribution -based [16], Naive-Bayes classifier [17], support vector machine [18], hidden Markov model [19], local SMQT (successive mean quantization transform) features and split up SNoWclassifier [20], information theoretical approach [21], and Haar classifier [22]. The authors compare the result of the face detection techniques. This is a continuation based on Yang et al.'s research [11]. To the authros' knowledge, there is no detailed survey about face detection after Yang et al.'s in 2002 (the above mentioned 2003 and 2005 survey papers concentrate on recognition aspects).

In Yang et al.'s survey paper [11], they compared the performance of face detection techniques by using the CMUMIT database, which consists of two data sets: Sung et al. [16] and Rowley et al. [15]. The first data set consists of 130 images with 507 frontal faces and the second set consists of 23 images with 155 frontal faces. In order to compare with Yang et al.'s experimental results [11, 23], the authors have excluded the hand drawn faces and cartoon faces in both sets. Therefore, Test Set 1 consists of 125 images with 483 faces and Test Set 2 consists of 20 images with 136 faces.

The authros contribute to the study by adding two latest techniques, i.e. SPLIT SNoW [20] and Haar classifiers [25] (as shown in Table 1, in bold font) to Yang et al. s experimental results [11]. The details of SPLIT SNoW and Haar's classifiers were discussed in more details in Yap et al. [26]. The comparison of some prominent face detection algorithms is presented in Table 1, and Fig. 1 visually illustrates the results of face detection when using SPLIT SNoW [26] and the Haar classifiers [25].

The results in Table 1 do not characterize how well these methods will compare in the field as all of them are based on different training sets and different tunin

**Table 1 Comparison of some prominent face detection algorithms.**

| Method | Test Set 1 | | Test Set 2 | |
|---|---|---|---|---|
| | Detection rate | False detections | Detection rate | False detections |
| Neural network [15] | 92.5% | 862 | 90.3% | 42 |
| Distribution based [16] | n/a | n/a | 81.9% | 13 |
| Naive Bayes [17] | 93.0% | 88 | 91.2% | 12 |
| SVM [24] | n/a | n/a | 74.2% | 20 |
| SNoW with primitive features [23] | 94.2% | 84 | 93.6% | 3 |
| SNoW with multi-scale features [20] | 94.8% | 78 | 94.1% | 3 |
| **SPLIT SNoW [20]** | **78.88%** | **114** | **66.92%** | **79** |
| Kullback relative information [21] | 98.0% | 1,2758 | n/a | n/a |
| **Haar Classifiers[22, 25]** | **93.38%** | **390** | **91.92%** | **26** |

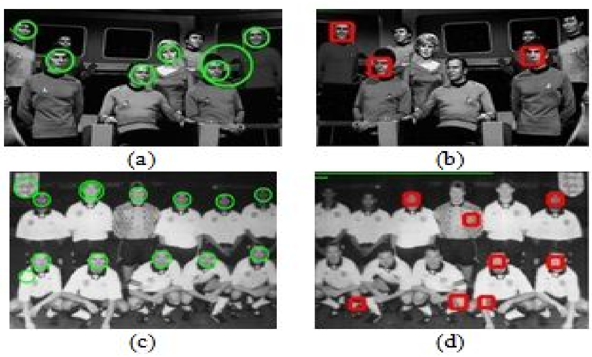


**Fig. 1 Face detection results on CMUMIT database: (a, c) by the Haar classifier, and (b, d) by SPLIT SNoW.**

-g parameters. As such, this is not a fair comparison as the training time and execution time are not taken into consideration. In addition, the number of scanning windows in these methods is varied. To prove the above statements, the authros run experiments on another benchmark data set, i.e. the BioID database [27]. The dataset consists of 1,521 gray level images with a resolution of 384×286 pixels. Each image shows the frontal view of a face of one of 23 different test persons [27].

Table 2 compares the detection results for the Haar classifier and SPLIT SNoW on the BioID database. The results are visually shown in Fig. 2. The high detection rates and low false detections for these techniques have indicated that they were designed for this specific application. Besides, some of the parameters are adjustable to optimise the application.

Face detection has achieved a mature stage through the Haar classifier, and some recent researchers [28-30] shown the reliability of the algorithms. The next step after locating the face is to analyse the facial expressions. The following section is to discuss facial expression analysis.

## 4. Facial Expression Analysis

Human faces can be defined as two eyes that are symmetric to each other; a nose; a mouth; a represention of the relationship between the features in relative distances and positions. This has presented a research problem in setting up rules to describe human faces. The overall expression of faces described by Hager [31] included: bony structures, shapes and positions of features, and colour and texture of the skin. The relatively permanent appearance of the face is formed by the shapes and placement of the bone of the skull, the cartilage, the soft tissues (the muscles, the fat, the skin) and the facial features they form (personality, well-being, character). Physiognomy of the face is the permanent facial features [31]. The concept of facial expression by Hager [31] is: a characteristic of a person that is presented (i.e. the signified) and a visual configuration that represents this characteristic (i.e. the signifier).

**Table 2 Experimental results on BioID database.**

| Method | BioID database | |
|---|---|---|
| | Detection rate | False detections |
| SPLIT SNoW [20] | 99.47% | 37 |
| Haar classifiers [25] | 97.76% | 187 |

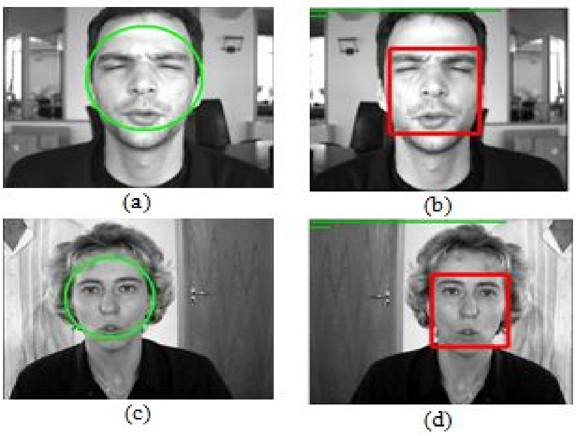


**Fig. 2 Face detection results on the BioID database: (a, c) by the Haar classifier and (b, d) by SPLIT SNoW.**

The physical base of this appearance is the skin, muscle movements, fat, wrinkles, lines, blemishes, etc. The expression of the face is the basic mode of nonverbal communication among people [31]. Facial expressions are created by muscular actions and continually evolve and propagate via both biological and cultural mechanisms [31]. Some early research includes:

- Darwin [32] who demonstrated the universality of facial expression and their continuity in man and animals. He claimed that there are specific inborn emotions, which originated in serviceable associated habits;
- Ekman and Friesen [33] postulated six primary emotions that poss each a distinctive content together with a unique facial expression. These basic emotions (happiness, sadness, fear, disgust, surprise and anger) seem to be universal across human ethnicities and cultures;
- Suwa et al. [34] presented a preliminary investigation on automatic facial expression analysis from image sequences;
- Mase and Pentland [35] produced pioneering work on advanced face detection, face tracking and face recognition using relatively low computational power.

Facial expression recognition should not be confused with human emotion (which is not uncommon in the computer vision community) [36]. Facial expression recognition deals with classification of facial motion and facial feature deformation into abstract classes that are purely based on visual information. Human emotions are a result of many different factors and their state might or might not be revealed through a number of channels (voice, pose, gestures, gaze direction, and facial expressions). Facial expressions are a key index of emotion. They have consistent correlation with self-reported emotions [37]. Besides, some confusion between face recognition and facial expression recognition also exist. The goal of face recognition is to find a similarity measure invariant to illumination changes, head pose and facial expressions so that images of faces can be successfully matched in spite of these variations [8]. Distinct from face recognition, the goal of facial expression recognition is to classify the expressions by finding a model for non-rigid patterns of facial expression. In addition, facial expression recognition is expected to perform better on image sequences than static images. For face recognition the authors compare the still image with the data in a database, but for facial expression recognition they consider psychological points of view in deciding the expressions type from image sequences.

Psychological points of view play an important role in facial expression recognition. Besides, some of the researchers investigate the physiological information in the thermal domain. Physiological information can be used to draw inferences about psychological states and health symptoms. Examples of some information that can be extracted are: localise blood flow, cardiac pulse, and breath rate [38].

### *4.1 Facial Expression Measurement*

Fasel et al. [36] achieved facial expression measurement by considering the location of facial action, intensity and dynamics. Intensity was measured by determining either the geometric deformation of facial feature or the density of wrinkles appearing in certain face regions. This was referenced to the neutral face. Dynamics are measured with the aid of four temporal parameters: neutral (inactive), onset (attack), apex (sustain), offset (relaxation).

Emotion is one of the most controversial topics in psychology as it is a source of intense discussion and disagreement from the earliest philosophers and other thinkers to the present day. Ekman et al. [39] discussed emotion using the following components; feeling, passion and sensation, which are the set of behaviours that may be performed and observed in conjunction with an emotion.

Six basic emotion-specified facial expression are defined by Ekman [39]: disgust, fear, joy, surprise, sadness, and anger. Generally, there are two types of approaches in facial expression analysis [40], namely, Message Judgement based approaches and Sign-based approaches. Message Judgement based approaches define facial expressions in terms of inferred emotion [40]. It uses an agreement of coders as ground truth and is trying to model the ground truth. Most of the literature attempts to use the basic emotion classes introduced by Ekman and Friesen [33]. Sign-based approaches are based on the target to achieve the goal of facial action coding system (FACS–foundation for describing facial expressions), developed by Ekman and Friesen [41].

### *4.2 Facial Action Coding System (FACS)*

There are three version of FACS: FACS 1978, FACS 1992, and FACS 2002. The FACS is the human-observer-based system designed to detect subtle changes in facial features [41], it is purely descriptive and uses no emotion or other inferential labels. It is a method to measure facial expressions by identifying the muscular activity underlying transient changes in facial appearance. The system defines 46 AUs (action units), which roughly correspond to the movement of each of the individual facial muscles. FACS is the leading method for measuring facial movement in behavioural science. FACS measurement units are AUs and not muscles because in a few appearances more than one muscle movement was combined into a single AU; the appearance changes produced by one muscle were sometimes separated into two or more AUs to represent relatively independent actions of different parts of the muscle. AUs are the smallest visually discriminable facial movement [42]. By using FACS and viewing videotaped facial behaviour in slow motion, coders can manually code all possible facial displays. AUs may occur in a single unit or in additive (independent) or non-additive (change each other's outlook) combinations.

FACS 2002 defines 9 AUs in the upper face, 18 in the lower face, 14 head positions and movements, 9 eye positions and movements, 5 miscellaneous AUs, 9 action descriptors, 9 gross behaviours, and 5 visibility codes. EMFACS (emotion FACS) and FACS Interpretive Dictionary coded emotion expression in separate systems [43]. FACSAID (FACS affect interpretation database) [31] is a tool for understanding what the muscular actions that FACS measures mean in terms of psychological concepts: it interprets the facial expressions in terms of meaningful scientific concepts. Physiognomy refers to features of the face, which are used to infer the relatively enduring character or temperament of an individual.

### *4.3 Facial Expression Image Databases*

There are a few facial expression image databases available for research. The most representative database is Cohn-Kanade AU-Coded Face Expression Image Database [44]. This is a large-scale database for promoting quantitative study of facial expression analysis [44]. The database consists of a recording of the facial behaviour of 210 adults who are 18 to 50 years old, 69% female and 31% male. Over 90% of the subjects had no prior experience in FACS. Subjects were instructed by an experimenter to perform single AU and AUs combinations. Subjects' facial behaviour was recorded in an observation room. Image sequences with in-plane and limited out-of-plane motion were included. The image sequences began with a neutral face and were digitized into 640 by 480 pixels arrays with either 8-bit gray-scale or 24-bit color values. 1,917 images sequences of 182 subjects have been FACS coded by certified FACS coders for either the entire sequence or target AUs. Approximately 15% of these sequences were coded by two independent certified FACS coders to validate the accuracy of the coding [45].

From psychology and human perception aspects, the authors survey the progress of automatic facial expression analysis from digital video input in the following section.

## 5. Automatic Facial Expressions Analysis

The goal of human-centred computing are to develop computer systems that can unobtrusively perceive and understand human behaviour in unstructured environments and respond appropriately [40]. Some studies in facial expression have been conducted in the last century [32, 46], and within the past 12 years considerable progress has been made in automatic analysis of facial expression from digital video input [36, 37, 40, 47]. In early research, Ekman et al. [48] reported a new method for describing facial movement based on the anatomical analysis of facial action. To capture subtlety of human emotion and paralinguistic communication, automated recognition of fine-grained changes in facial expression is needed [45].

Early work in automatic analysis and recognition of facial actions from input video focused on the relatively tractable problem of posed facial actions acquired under well-controlled conditions. Recent work has progressed to spontaneous facial actions, subtle facial actions, variation in illumination, and merging with synthesis faces (i.e. avatar separate identity from facial behaviour) [40]. Computer facial expression analysis systems need to analyse the facial actions regardless of context, culture, gender, and so on. The accomplishments have been in psychological studies, human movement analysis, face detection, face tracking, and automatic facial expression analysis [47].

Lien et al. [49] extracted feature information in three modules: dense-flow extraction using a wavelet motion model, facial feature tracking, edge and line extraction. Then, they fed the features into discriminant classifiers or Hidden Markov Models that classify the information into FACS action units (the descriptive system to code fine-grained changes in facial expressions). They concluded with manual FACS coding, and correlation between dense-flow extraction and facial feature tracking was strong, but strong to moderate for edge and line extraction.

Bartlett et al. [50, 51] applied computer image analysis to the problem of automatically detecting facial actions in sequences of images. Three approaches were compared: holistic spatial analysis, explicit measurement of features such as wrinkles, and estimation of motion flow fields. The three methods were combined in a hybrid system that classified six upper facial actions with 91% accuracy. The hybrid system outperformed human non experts on this task and performed as well as highly trained experts. An automated system would make facial expression measurement more widely accessible as a research tool in behavioural science and investigations of the neural sub-states of emotion.

To analysis real-time facial expressions more effectively, motion analysis is important as the temporal changes, or changes in image sequences are important in classifying the expression types.

## 6. Face Tracking and Motion Analysis

Motion plays an important role in detecting and tracking the head and face, and within the face, tracking the motions or deformations of the permanent features and transient features of the face. Temporal changes in facial expressions observed through motion analysis may carry important information.

Visual object tracking [52] addresses the problem of locking onto the object in question in an image sequence despite its changes in pose, size, illumination, and even appearance. Motion analysis [37] is concerned with estimation of non-rigid motion within the parts of the object being tracked.

In early tracking system, e.g. in Refs. [52-54], feature matching was carried out from one frame to the next using optical flow computations. The optical flow approach has the advantage of not requiring a feature detection stage. However, it might result in drifting errors accumulating over long image sequences. Optical flow is the visible result of movement and is expressed in terms of velocity, it is a direct representation of facial action [35, 54]. Muscles actions can be directly observed in image sequence as optical flow, which is calculated by facial features and skin deformation [55]. Dense flow information was computed from image sequences of facial expression with Horn et al.'s [56] basic gradient algorithm, which was then reduced by taking the average length of directional components as the major directions of muscle contraction. Several muscle windows are located manually to define each muscle group using feature points as references. The muscle action derived from the muscle (group) model can be associated with several AUs of the FACS. In Mase's [35] experiment, he managed to identify 19 out of 22 test data in recognizing four expressions (happiness, anger, surprise and disgust).

## 7. Proposed Solution on Visual Cues

Based on the authors' survey, they propose a basic model for surveillance applications. From Section 3, the authors found that the Haar classifier implemented in OpenCV (open source computer vision library) [25] is the best face detection algorithm for real-time application (Table 1 and Table 2). Hence, the authors suggest the implementation of the Haar classifier for face detection. To find a promising solution, they have done a thorough survey in facial expression analysis. As a result, the authors found a constructive way of expressions recognition, i.e. the authors proposed to implement a solution based on FACS (facial action coding systems). FACS has been well recognised in the world of psychology and it is vastly implemented [51].

Fig. 3 illustrates the authors' proposed solution. First, they detect faces in image sequences, extract the features from the face area, and classify the features parameters into upper face action units, lower face action units and eye positions. Subsequently, the authors classify the six basic emotions based on the FACS guidelines. The outputs of this process are types of emotions, action units and eye positions. Further analysis will involve psychological aspect to combine the cues and relate these to threat behaviour prediction. In short, the ultimate goal is to implement the concept into the current prototype to have a real time system in detecting threating (or generic abnormal) behaviour. This could be further extended in the future to investigate into micro facial expression.

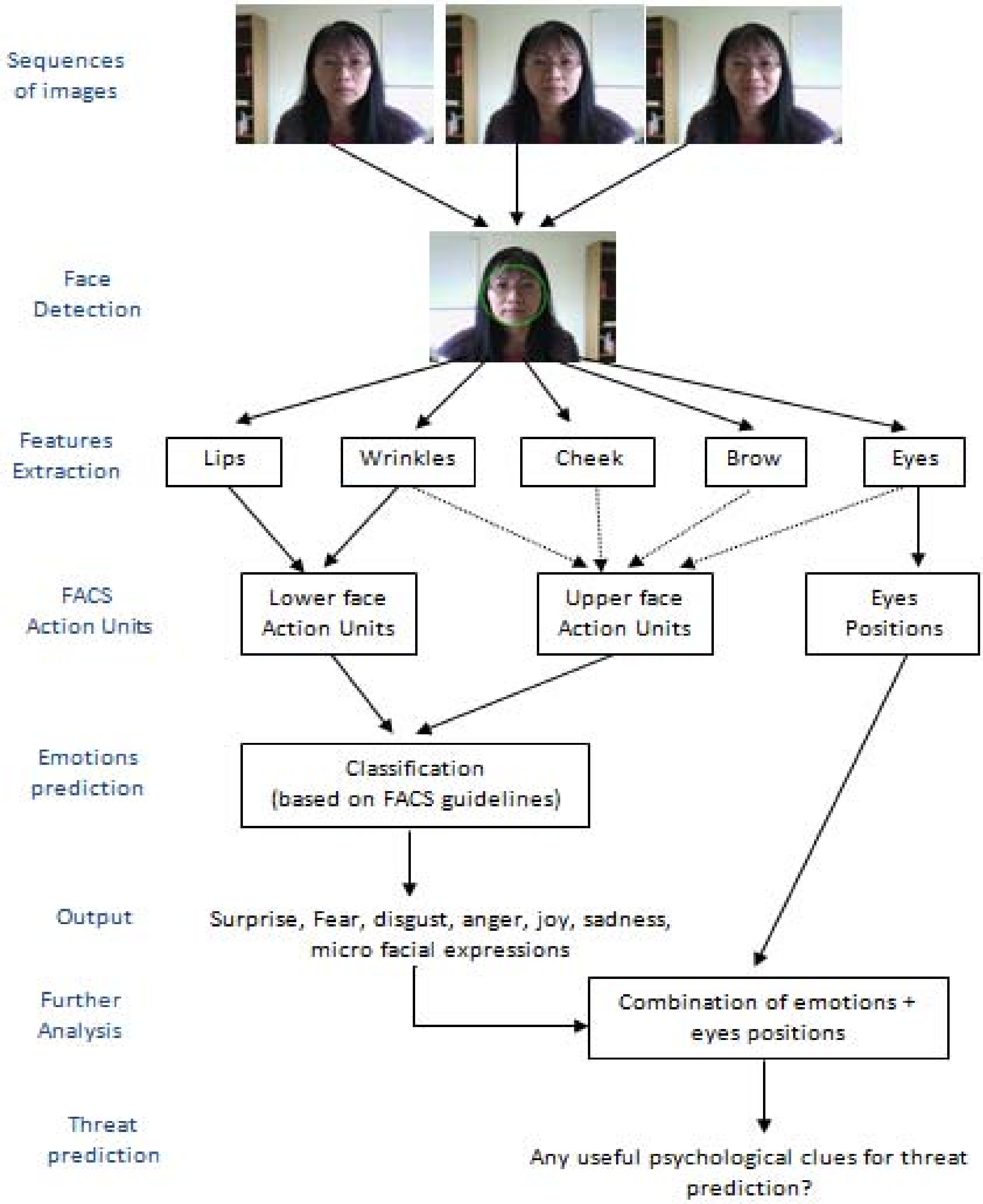


**Fig. 3 Diagram illustrates the proposed solution for visible cues.**

## 8. Conclusions

Facial analysis is multi-disciplinary research and it provides important cues for predicting human behaviour. In this paper the authors have compared the performance of face detection algorithms on different source of images. They found that the performance of the algorithms is varying from dataset to dataset. This finding confirmed the nature of computer vision algorithms: different pipeline produces different result, and the challenge in obtaining a consistent algorithm across different datasets. Based on the speed and ability in handling real-time processing (as shown in many research works [28-30]), the authors have implemented OpenCV's Haar Classifier in their face detection prototype and they aim to enhance the performance in the future. On the other hand, detailed survey in facial expressions analysis, automated facial expressions analysis and face tracking system was conducted. Based on the survey, the authors understand that facial expressions analysis is expected to perform better in image sequences/video. They believed that FACS provides the best guidelines for using visual cues. In conclusion, the major challenge in facial analysis is to detect the subtle changes in the face, especially changes in wrinkles, furrows and micro-expressions.

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