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Recognizing faces prone to occlusions and common variations using optimal face subgraphs

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A R T I C L E I N F O

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A B S T R A C T

An intuitive graph optimization face recognition approach called Harmony Search Oriented-EBGM (HSO-EBGM) inspired by the classical Elastic Bunch Graph Matching (EBGM) graphical model is proposed in this contribution. In the proposed HSO-EBGM, a recent evolutionary approach called harmony search optimization is tailored to automatically determine optimal facial landmarks. A novel notion of face subgraphs have been formulated with the aid of these automated landmarks that maximizes the similarity entailed by the subgraphs. For experimental evaluation, two sets of de facto databases (i.e., AR and Face Recognition Grand Challenge (FRGC) ver2.0) are used to validate and analyze the behavior of the proposed HSO-EBGM in terms of number of subgraphs, varying occlusion sizes, face images under controlled/ideal conditions, realistic partial occlusions, expression variations and varying illumination conditions. For a number of experiments, results justify that the HSO-EBGM shows improved recognition performance when compared to recent state-of-the-art face recognition approaches.

1. Introduction

Automatic face recognition has been a subject of intensive research for the past few decades. It is the problem of recognizing humans by matching a given face with face images stored in a database. As an interest, it is a challenging task where the performance of a typical face recognition algorithm usually degrades considerably due to several variations such as expressions, illumination conditions and facial occlusions [15,32]. Therefore, developing a robust face recognition system amidst these variations is still an open research area as stated in recent studies [1,12,17,45]. Face recognitions systems have an essential role in biometric-oriented video surveillance systems which have been progressively incorporated in operational environments where the problem of encountering occlusions cannot be avoided [38].

Several approaches have been proposed to overcome the shortcomings of face recognition challenges: expressions, illumination conditions and facial occlusions [16,28,30,38,41,42,44]. In general, occluded face recognition approaches are classified into two categories: holistic and component-based. Holistic category manipulates the face image as a whole

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entity. In contrast, component-based category deals with occlusions by matching local regions rather than matching the whole entity [10]. Furthermore, in component-based approaches, the face image is partitioned into various segments and each segment is tackled independently. These models deal with occlusion by detecting the occluded areas then the results are manipulated by either reconstructing or discarding these areas. Notably, it has been observed that the reconstruction approaches such as [14,23,24] are not effective in the presence of large occlusions because the identity information can be contaminated during in-painting [39]. Omitting occluded areas in the face recognition might lead to loss of information but considering these areas might be discriminative and could increase the overall recognition rate.

Among the face recognition approaches which are holistic in nature, the Elastic Bunch Graph Matching (EBGM) is one of the most successful graph-based technique [11,36,40]. EBGM has been successfully applied for a wide range of face recognition problems [34]. However, it suffers from a major drawback whereby manual landmark selection is required in the initial stage of the recognition process. The automation-based systems require the modern face recognition systems to be totally automatic without the need to any intervention from the human side; for example the manual selection of the facial landmarks. One of the focus point of this study is to reformulate the EBGM as an optimization problem with the aid of Harmony search (HS) so as to compute optimal facial landmarks in an automatic way.

Human faces have useful facial landmarks that possess various information. Furthermore, psychological studies in face recognition [37] demonstrate that some facial landmarks are distinguished and more beneficial than others in terms of recognition accuracy. Thus, finding the optimal facial landmarks from the whole face image is required for efficient recognition. To cope with these issues, the meta-heuristic search techniques are most suitable to automatically determine the optimal facial landmarks.

Harmony search algorithm (HSA) is a recent meta-heuristic algorithm inspired from the music improvisation process [21]. It has several advantages over other metaheuristic-based approaches due to its derivative-free characteristics [20]. Therefore, HSA has been successfully tailored for a wide range of optimization problems such as timetabling [5–7], bio-informatics [3], image enhancements [9], scheduling problem of multiple dam system [19] and structural optimization [27] and many others as reported in [8,29]. In the face recognition domain, HSA was primarily used for feature selection problems [25,35] where using HSA on feature selection has shown improvements in terms of recognition accuracy.

In this study, a transformed image recognition approach is proposed based on HSA and component-based EBGM. This method is abbreviated as *Harmony Search Oriented-EBGM (HSO-EBGM)* which is able to automatically determine the optimal facial landmarks using HS. These potential landmarks serve as inputs for the modified EBGM face recognition approach which intends to recognize faces prone to several challenges such as occlusions, varying illumination conditions and facial expressions. The proposed component-based EBGM enables the model to tackle these challenges without demanding any prior knowledge or assumption about the occluded regions in the targeted face image. Interestingly, the component-based mechanism deployed in the proposed HSO-EBGM for handling partial occlusions neither discard any occluded region from similarity calculation, nor reconstruct this occluded region.

The effectiveness of the proposed HSO-EBGM method is evaluated using the AR [31] and Face Recognition Grand Challenge (FRGC ver2.0) [33] databases. The experimental results have shown that the proposed HSO-EBGM method can improve the accuracy of recognizing faces prone to occlusion and other variations such as expression and illumination. For comparative evaluation, the performance of the proposed HSO-EBGM is compared against the standard EBGM [11] and another five state-of-the-art-methods including Psychophysically Inspired Similarity MApping (PISMA) [38], Line Edge Map (LEM) [18], Ensemble String Matching (ESM) [13], Adaptively Weighted Sub-Gabor Array (AWSGA) [23], and Adaptively Weighted Patch Pseudo Zernike Moment Array (AWPPZMA) [24] using AR and FRGC ver2.0. The comparative results show that the proposed methods excels the comparative methods in almost all cases.

This paper is organized as follows: Section 2 provides a description of the Elastic Bunch Graph Matching (EBGM). The formulation of the facial occlusions problem is presented in Section 3. In Section 4 the proposed method is illustrated. Next, Section 5 reports the experimental results and discussions on the findings. Finally, we conclude the work and briefly suggest future research directions in Section 6.

2. Elastic Bunch Graph Matching (EBGM)

Elastic Bunch Graph Matching (EBGM) algorithm presented by Bolme is one of the mainstream face recognition algorithms [11]. In the initial stage of the EBGM implementation, sample set of images have to be chosen referred as model images. These images should account for different face image variations such as variations due to gender, race, and age; in addition to faces with open eyes, closed eyes, sunglasses and so on. Then, for each image, facial landmark points such as eyes, mouth and nose are chosen manually. Thereafter, The Gabor wavelets transform are extracted for each manually selected landmark and named as a jet (as shown in Fig. 2). The jets that were extracted from the model images are called model jets. Model jets are gathered in a data structure called Face Bunch Graph (*FBG*) as shown in Fig. 3. Each node of the bunch graph contains a set of M jets where M is the number of model images (70 image were used [11]). One of the advantages of modeling a bunch graph is that there are different instances of landmarks that are stored in the corresponding bunches. For example model jets of eyes with glasses, eyes that are closed/opened and eyes under different lighting are available. Furthermore, the jets from different individuals for each landmark on the face were provided. The FBG is used for landmarks localization in the novel image where the node positions on the new image is estimated using the average values of node positions of the FBG. The node positions are refined by calculating the similarity between jets from estimation