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A comparative study of preprocessing mismatch effects in color image based face recognition

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ABSTRACT

Face color information can play an important role in face recognition (FR) and it can be used to considerably improve FR performance obtained using only grayscale images. The color-based FR methods involve a preprocessing step where a color image is converted into either a monochromatic image or an image having a different color representation. In practical FR systems, the recording or transmission format of the testing images may be arbitrary or inconsistent depending on the application (e.g., face images could consist of grayscale or color pixels either in compressed or uncompressed form). Further, a wide variety of grayscale and color conversions can be used in the preprocessing step. This could lead to a so-called preprocessing mismatch in color-based FR methods: the training and testing face images, generated after preprocessing, do not match in terms of their degree of compression or in terms of their grayscale or color representations. In contrast to grayscale-based FR, a practical color-based FR system has a higher chance of being confronted with a preprocessing mismatch. The aim of this paper is to present a comparative study that addresses the impact of a preprocessing mismatch on color-image based FR methods. We explore three different types of preprocessing mismatches, which practical color-based FR system are highly likely to encounter. In addition, comparative and extensive experiments have been carried out to analyze the effects of the preprocessing mismatches on an FR performance, using Color FRETET, CMU-PIE, AR, and SCface public face databases. The important conclusions drawn from our experiments include: (1) of all color-based FR methods under consideration, color-based FR using feature-level fusion is the most robust approach to preprocessing mismatches; (2) the preprocessing mismatch caused by the use of compressed color images can significantly deteriorate FR performance of color-based FR methods; (3) grayscale testing images can be critical for the feasibility of color-based FR using an input-level fusion; (4) the preprocessing mismatch in terms of grayscale representation has little effect on the FR performances of color-based FR methods.

1. Introduction

Most face recognition (FR) methods have been developed under the assumption that face image sets consist of grayscale still images. Indeed, the use of grayscale images is a common practice for conventional FR applications, such as video surveillance and authentication [1]. Recently, however, considerable research efforts have been dedicated to the development of FR methods that utilize *face color* information [2–17,63]. Results reported in these works indicate that *face color* information can play an important role in FR and it can be used to considerably enhance FR performance [2–17,63].

The general framework of color-based FR methods consists of the following modules in common [7], as outlined in Fig. 1: preprocessing, input vector construction, the creation of a feature extractor, feature extraction, and classification. The creation of a feature extractor is done during the training stage, while feature extraction and classification are performed during the testing stage. Note that classification step in general includes multimodal analysis [28], which integrates information from different color bands for an FR purpose. It should also be noted that the *preprocessing* and the *input vector construction* modules are common to both the training and testing stages (a detailed description of preprocessing and input vector construction is presented in Section 3). As shown in Fig. 1, in a typical color-based FR, a feature extractor is created using a training set comprising *RGB* color images [16,63] and subsequently the resulting feature extractor is deployed during the testing stage for obtaining the face features of testing images (note: throughout the remainder of

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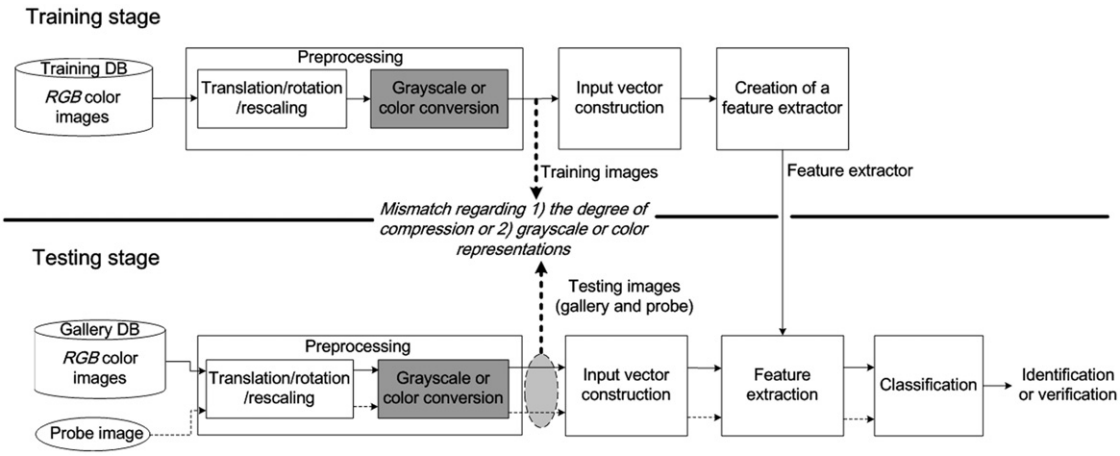

Fig. 1. Generic framework and preprocessing mismatch problem of color-based FR methods.

this paper, the term "testing images" are used to indicate "both gallery and probe images"—when used during the testing stage). In general, prior to the creation of a feature extractor or the actual extraction of features, both training and testing images are passed through a common *preprocessing* step. In contrast to grayscale-based FR, this preprocessing step typically involves *grayscale or color conversions*, which means that a color image is converted into either a monochromatic image or a color image that is represented using a different color space [7,8,12–16].

In practical applications, the recording or transmission format of the testing images in question may be an arbitrary or inconsistent (e.g., face images could consist of grayscale or color pixels either in compressed or uncompressed form [18,19]). Further, a wide variety of grayscale and color conversions could be used in the preprocessing step [63] as different color models possess distinct characteristics and effectiveness in terms of discriminant capability depending on underlying FR operating conditions [20], such as an illumination variation. This can frequently lead to a so-called *preprocessing mismatch* in practical color-based FR systems. In particular, a preprocessing mismatch typically arises when the feature extractor phase utilizes training images that differ from the testing images. In this paper, therefore, a preprocessing mismatch problem is defined as follows: a mismatch between training and testing (i.e., gallery and probe) images, outputted by a preprocessing module, in terms of their *degree of compression* or in terms of their *grayscale or color representations* (see Fig. 1).

Although a number of color-based FR methods have been proposed, we have not found any systematic studies on addressing the effect of a preprocessing mismatch in color-based FR. The aim of this paper is to provide insight into the importance of a preprocessing mismatch when color-based FR methods are applied to real-life applications. In particular, the main contribution of our paper is twofold as follows:

- We explore the following three different types of preprocessing mismatches that are more likely to occur in practical color-based FR systems: (1) preprocessing mismatch caused by *grayscale* testing images; (2) preprocessing mismatch caused by *compressed* images; (3) preprocessing mismatch caused by the use of different *grayscale* or *color space conversions* (for more details, please refer to Section 4 that explains the aforementioned preprocessing mismatch types, along with their associated real-world FR applications and corresponding illustration figures that visualize the occurrence of each preprocessing mismatch type). The exploitation of potential preprocessing mismatches in our study will benefit FR practitioners in that they can readily recognize them in their target FR applications. This is of crucial importance because a preprocessing mismatch problem, in contrast to other factors such as illumination and pose variations, would be as *latent* as FR designers can often overlook.
- Comparative and extensive experiments have been carried out to investigate the influence of preprocessing mismatches considered on FR performances of representative color-based FR methods. To perform extensive experiments, more than 4000 color images of 446 subjects were collected from four public face databases (DB): color FERET [22], CMU-PIE [23], AR [24], and SCface [67]. Based on our experimental results, we analyze which preprocessing mismatch is critical or trivial in terms of deteriorating FR performance with respect to different color-based FR methods. Further, we exploit which color-based FR method is robust to preprocessing mismatch problems considered. In particular, the important conclusions from our experiments include: (1) color-based FR using feature-level fusion is the most robust approach to the preprocessing mismatches of all color-based FR methods considered; (2) the preprocessing mismatch caused by the use of compressed color images can significantly deteriorate FR performance of color-based FR methods; (3) grayscale testing images can be critical for the feasibility of color-based FR using input-level fusion; (4) the preprocessing mismatch in terms of grayscale representation has little effect on FR performances of color-based FR methods.

Section 2 reviews previous work on face recognition using color images, emphasizing the usefulness of color information for FR. In Section 3, the color-based FR methods used in our study and their preprocessing steps are reviewed. Section 4 outlines three different types of preprocessing mismatches for the color-based FR methods reviewed in Section 3. In Section 5, we present experimental comparative study with face databases and experimental conditions, which answers the questions raised in Section 4. The important findings from our study are summarized and also the effectiveness of our results in the context of practical applicability is discussed in Section 6. The conclusions and future research directions are presented in Section 7.

2. Previous works in color-based face recognition

Face recognition using color information is a relatively new research topic in the area of automatic FR. Previous work can be