Analysis of the Effects of Image Transformation, Template Selection, and Partial Information on Face Recognition with Time-Varying Expressions For Homeland Security Applications

Iliana V. Voynichka , and Dalila B. Megherbi

CMINDS Research Center, Department of Electrical and Computer Engineering, University of Massachusetts, Lowell, MA 01854 USA,

Abstract— Facial recognition, especially with time-varying facial expressions and/or disguises, is crucial in many homeland security applications. The recent Boston Marathon attack is one example reminder of the importance of developing accurate and reliable facial recognition algorithms. While various face recognition algorithms have been proposed in the literature, unfortunately many of them still remain in their infancy. This is mainly due to their lack of high recognition rates in the presence of varying image face artifacts and conditions. In order to develop more accurate facial recognition systems there is a primary need to identify and, as much as possible, derive some of the causes that may affect some face recognition accuracy rates. The main contribution of this paper is the investigation and analysis of how and what factors, other than illumination noise, and occlusion, may affect the recognition accuracy rate of some of the most popular and currently widely used face recognition algorithms, namely, Eigenface-based, Fisherface-based and Direct Correlation-based ones. In particular, in this work we show the effects, on these facial recognition accuracy, of facial reasonable registration with or without off-the-plane face rotation, the type and number of individual's face template(s) selection, and the type and increasing amount of partial facial information contained in face images. Finally experimental results are presented to demonstrate the potential value and importance of each of these proposed factors on facial recognition.

Keywords—component; Machine Learning, Computer and Machine Vision, Computational Intelligence; Digital Image Processing, Facial Recognition, Biometrics, eigenfaces, fisher-faces, correlation-based face recognition.

I. INTRODUCTION

Facial recognition is a complex visual task that humans can perform with high accuracy and precision under variable and harsh conditions. Attempts have been made and research is still ongoing to design a robust machine based system that can recognize faces just as efficiently and accurately as humans. The task of recognizing a human face is made more difficult by the fact that the same person can look substantially different in the presence of facial expressions, disguises, illuminations, occlusions, etc. This makes the design of such a system a challenging problem.

Furthermore, face recognition is a challenging task because face images are fairly similar due to the same geometrical configuration of facial features. This leads to the requirements of fine discriminatory techniques to discern among faces.

These two difficulties call for novel recognition technique that can distinguish the various differences in the configuration of features, while at the same time being able to recognize the same face with a different facial appearance.

In particular, face recognition has received a lot of positive attention in relatively recent years [18-49] – the availability of reliable technologies and the relative low cost of a face recognition systems have made it a popular biometric in the areas of security and surveillance. In addition, compared to other biometric methods that require the cooperation of the subject such as fingerprint analysis or iris scan, face recognition can be performed from a distance and without the knowledge of the participants.

Research in the field of face recognition has been ongoing for more than thirty years and the field is still rapidly growing. It has yielded numerous more or less reliable techniques that perform with relatively good accuracy in a given environment and under some predefined conditions. One primary challenge is that no one method provides a solution that performs with high accuracy in all situations, under varying conditions and environments in the way the human visual system does. In particular, there are many factors that affect the recognition accuracy of facial recognition algorithms.

Some of the most widely used facial recognition techniques are Fisherface-based, Eigenface-based and
Direct Correlation-based recognition. These methods are effective but are greatly affected by noise, illumination, occlusion and other artifacts. Even though these techniques have been very widely used and very popular, to our knowledge, what additional factors affect their accuracy have not been accordingly studied. To build better, more robust, and more accurate face recognition algorithms there is a need to investigate, identify, and understand better what factors may affect their accuracy.

A. Paper Objective and Contribution

In our previous work [9][32-37], we presented various analyses of artifacts such as image illumination on face recognition [9][32-37], and the effect of feature selection [35][36][37] on machine-learning-based-object representation and recognition. The main aim in this paper is the study and the investigation of how and what factors, other than illumination, noise, and image occlusion may affect the recognition accuracy rate of the most popular and currently most widely used face recognition algorithms, namely, Eigenface-based, Fisherface-based and Direct Correlation-based facial recognition methods. In particular, we show the effects of facial reasonable registration with or without off-the-plane face rotation, the number and types of individual template(s) selection, and the increasing amount and type of increasing partial facial information contained in face images, on the face recognition accuracy.

B. This Paper Organization

The rest of the paper is organized as follows. In Section II we present image faces preprocessing as well as the challenging face data set, with time-varying expressions, used in our experiments in this paper. In section III we present the study and analysis of the effect of partial information, registration, and template selection on face recognition. Section IV presents our discussions, conclusions and future work.

II. IMAGE FACE PRE-PROCESSING AND DATA SETS

For the purpose of our study and analysis of the effect of partial information, registration, and template(s) on face recognition accuracy, we the challenging ORL data base, shown in Fig-1. It is comprised of very challenging faces with various artifacts, including in-the-plane affine transformations, and off-the-plane rotations, various illumination conditions, disguises and facial expressions.

This data set is comprised of 400 images representing 40 individuals, each with 10 varying face time-varying expressions, and off-the-plane face rotations. As mentioned above for face recognition algorithms testing, we consider the popular widely used Eigenface, Fisherface, and correlation ones.

In order to study the effect of image registration of this ORL data set, registration of all images with respect to a reference image is first performed. The algorithm, depicted in Table-1, is used for that purpose. Fig-2 and Fig-3 show respectively face image registration results using the algorithm in Table-1, and the resulting ORL database of the 400 registered faces.

For partial image information on face recognition, we consider two partial shapes in this paper, namely rectangles and ellipses with varying sizes. Fig-4 shows examples of the resulting rectangle and ellipse face partial information databases, used in this study. One may note, in Fig-4, the black space around the registered image — this is a result of image registration.

After registration, the resulting images have different sizes and the images have to be padded to make them all of the same size. Fig-5(a) and Fig-5(b) show respectively the resulting partial rectangle-based information face database, and resulting partial ellipse-based information database.

Fig-1: The challenging ORL face database (raw data) used in the experiments
Algorithm 1: Image Registration Algorithm

1. For every image in the database \(|I_i|\), where \(i = 1, 2, 3, \ldots, q\)
   a. Read in original image \(|I_i|\)
   b. Read in base image \((B)\)
   c. Execute the point selection
   d. Select the control points – both eyes and nose in both input image \(|I_i|\) and base image \((B)\)
   e. Execute the adjustment of each pair of control points based on cross-correlation
   f. Derive the affine transformation
   g. Transform the test image

Table 1: Image registration algorithm used to originate the registered face database used in this work.

III. STUDY AND ANALYSIS OF THE EFFECT OF PARTIAL INFORMATION, REGISTRATION, AND TEMPLATE SELECTION ON FACE RECOGNITION ACCURACY

A. Study and Analysis of the Effect of Image Registration on Face Recognition

We performed machine learning face recognition based on a 60%-size training data set and a 40%-size size external validation testing data sets, out of a total of the ORL 400 faces. Face recognition accuracy results for the three considered facial recognition methods, fisher-face, eigen-face, and correlation-based, are shown in Fig 6. One may observe that for all three types of face recognition accuracy, the registered partial-information-based images always resulted in better face recognition accuracy. In particular, as the results show, for the challenging ORL database considered in this study, whole registered images do not perform as well as raw whole images. This stems mostly, and as noted in section III, from the resulting black space around the face after image registration is performed, as shown in Fig-4. When the black space is removed, when considering partial face information by cropping a given image into a rectangle or an ellipse, the registered image yields better results than the full raw images.

B. Study and Analysis of the Effect of the Type and Number of Training Template(s) Selection

As shown in Fig-7 all the three-above-mentioned methods for facial recognition virtually performed better when the number of used templates per individual increased from one to six. The experiment was run on a database set containing only one training template per individual, as well as on a set containing 6 templates per individual (multi). All three methods perform better when the number of training templates is increased. The results show that selecting more than one template with more face configurations per individual, results in better facial recognition rate.

C. Study and Analysis of the Effect of Varying the Amount of Information cropped off the face on the Recognition Accuracy

Here we investigate the effect on face recognition of increasingly varying the amount of information contained in an Image by cropping an increasingly growing-in-size part of a given face. Facial recognition accuracies are given in Fig-8.

For this experiment, partial images containing different amounts of information are used. The partial images are obtained by cropping the original image into a square or an ellipse containing the central part of the face. The size and center point of the ellipse and square are then varied to obtain the different increasing-in-size partial images. The
percentage of information contained is calculated by dividing the number of pixels in the resulting image by the number of pixels in the original image. Only in the case of Fisherface-based method and images containing 62% of the information, that the partial image outperforms the whole image. Fig-9 shows the effect of varying the amount of information in an image on the recognition accuracy when no significant off-the-plane face rotation is allowed. For this experiment, images with off-the plane rotation are removed (as a result the training set is reduced from 240 to 149 images) and the three facial recognition methods are applied again. In this case the results show that partial images containing 24%, 34% and 49% of the original information outperform the whole image.

Fig 5 (a) Resulting partial information rectangle-based face database (b) Resulting partial information ellipse-based face database.

Fig 6 : Recognition accuracy of Eigenface-based (a), Fishreface-based (b) and Direct Correlation-based (c) methods for raw images vs. registered images.

Fig-7 Effect of the number of training templates on the recognition rate..
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![Fig-10: Example of the partial images yielding better accuracy: (a) 49%; (b) 34%; (c) 24% The image in (c) does not contain the mouth and still yields better recognition accuracy than in the case when the whole face is used.](image)

![Fig-11: Recognition accuracy for images that contain the eyes and nose and for images that do not.](image)

Fig-10 below, shows an example of partial face images that resulted in better accuracy in the case of limited off-the-plane image rotation, while Fig-11 shows the effect on face recognition accuracy, of varying the amount of information contained in an image by cropping part of the face.

![Fig-8: Effect of varying the amount of information in an image on the recognition accuracy.](image)

![Fig-9: Effect of varying the amount of information in an image on the recognition accuracy (no off-the-plane rotation).](image)

IV. CONCLUSION AND FUTURE WORK

The effects that various factors, other than illumination, noise, and image occlusion, have on the accuracy of the most popular and currently widely used facial recognition algorithms, namely, Eigenface, Fisherface and Correlation methods, were investigated and studied in this paper.

First, we looked at the image registration factor, with or without off-the-plane-face-rotation, and observed that registered images yield better recognition performance; however due to the degree of off-the-plane image rotation, face image registration may become ineffective in improving face recognition. The results show that registered images yield better recognition rate in general. This was particularly the case when artifacts related to off-the-plane face rotation were minimized.

Second, we looked at the effect that varying the type and number of training image templates has on the facial recognition rate. The findings showed that for the challenging ORL face Database used in this paper, as the number of training templates (with varying face configuration) increases, the facial recognition accuracy improves.
Lastly we investigated the effect that the increasing amount and type of information contained in the image have on the recognition rate. We showed for instance that an image that only consists of the central part of a face containing eyes and a nose, performs better in general than an image containing the whole face.

Future work includes but is not limited to investigating the effects of the same factors on face verification in respect of false positives and false negatives. Future work also includes the study of the effect of selecting partial information of a face image has on the recognition accuracy of facial expressions in occluded faces.

References


