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Mechanisms for increasing the efficiency of holistic face recognition systems

Abstract*. In holistic face recognition systems face is represented by set of features derived directly from brightness of 2D image pixels. To ensure proper representation of face under variability in head rotation, lighting and expression many templates should be provided. Mechanisms for increasing the efficiency of holistic face recognition systems are considered. By expanding the base structure with additional function blocks, without incorporating intricate feature extraction methods, it is possible to increase the effectiveness of the system.*

Streszczenie. *W systemach rozpoznawania twarzy opartych na cechach holistycznych (globalnych) twarz jest reprezentowana poprzez zbiór cech wyliczanych bezpośredno z jasności pikseli obrazu 2D. Takie rozwiązanie wymaga odpowiedniej liczby wzorców, aby zapewnić właściwą reprezentatywność twarzy przy obrotach głowy, zmiennym oświetleniu i różnorodności wyrazów twarzy. Mechanizmy zwiększania skuteczności rozpoznawania w tego typu systemach są rozważane w artykule. Poprzez rozszerzenie bazowej struktury za pomocą dodatkowych bloków funkcyjnych, bez wprowadzania skomplikowanych metod ekstrakcji cech, możliwa jest poprawa skuteczności działania systemu (****Mechanizmy poprawy skuteczności holistycznych systemów rozpoznawania twarzy****).*

Keywords: face recognition, feature extraction, holistic face recognition system.
Słowa kluczowe: rozpoznawanie twarzy, ekstrakcja cech, systemy rozpoznawania twarzy oparte na cechach holistycznych (globalnych).

Introduction

The problem of face recognition has been known for decades and today new successful solutions appear in everyday life. Face recognition systems have a wide range of applications related to security, access control, law enforcement and commercial use [1]. Many of these applications have a great potential and are willingly used by many people. Users can login to their computers or smartphones simply by looking at the screen. People are identified at borders using a biometric passport. More and more social networks offer face recognition functionality on their web pages. Face recognition also begins to replace traditional approaches in complex problems like pedestrian traffic distribution analysis in big public transport interchanges [2].

Despite the maturity of the technology, which manifests itself in the form of existing solutions, it is still a lot of problems to solve. Although face recognition under controlled conditions is regarded as solved, it still remains a number of issues for consideration: liveness detection, one sample problem, intra-class variability and inter-class similarity, facial shape and texture change over time, facial expression, pose, illumination, occlusions and other unfavourable conditions. The problem of face recognition is still complex and challenging. New ideas to use individual characteristics of the face – face marks [3] – emerge. There are also new applications which require new approaches: facial sketch recognition [4], real-time searching of large face databases in real-time and many others.

In last decades numerous methods of biometric data extraction were invented and new systems of face analysis were proposed. Many of those are advanced and complicated. In this article emphasis is placed on the ability to increase the effectiveness of the system which uses holistic features of the face. By expanding the base structure of the system with new function blocks it is possible to noticeable improve the overall accuracy of the system. Comparable results with the latest developments reported in the literature can be achieved without changes in feature extraction.

The base structure of the face recognition system

There are two elementary tasks in face recognition [1, 5, 6]: identification and identity verification. While the first one tries to specify the identity of a person using the database of known individuals the second checks provided identity with the means of face image. The basic difference is in the comparison process: one-to-many in the first case and one-to-one in the second. Here, we will focus on face identification system.

Basic structure of an automated person identification system is presented in Fig. 1. It consists of three fundamental blocks [1, 5]: feature extraction, database and classifier. Face detection block is complementary. Its task is to analyse input image for the presence of a face and if present, its coordinates are provided and cropped face image is transferred further. In some cases systems operate directly with cropped face images and the face detector block can be omitted.

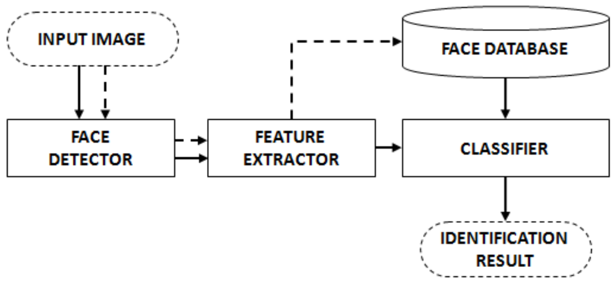

Fig.1. Basic structure of face recognition system

The core element of the system presented in Fig. 1 is feature extractor. The goal of the feature extractor is to find a specific representation of the face image. It is the most important step in face recognition. From the input face image only relevant information are preserved in resultant feature vector. These feature vectors are stored in face database and compared in the classifier. Two types of lines can be distinguished in the structure of the system: dotted and regular. The first reflects the operation of the system in the registration mode when users are enrolled to the database. The second denotes system operation in the identification mode.

There are three main groups of face recognition methods [1, 5, 7-9]:
- feature-based approaches,
- appearance based approaches,
- 3D approaches.

The main objective in the first group methods is to use anthropological face properties. Graph models and 2D elastic face are examples from this group. In appearance based approaches, also called holistic approaches or global approaches, face is represented by set of features derived directly from brightness of 2D image pixels. Classical eigenfaces and fisherfaces are examples here [1, 6]. Frequency domain analysis methods (DFT, DWT, DCT) also belong to this group [7, 11, 15]. In the last group a 3D model of a face is used [12-14]. 3D approaches have the potential under uncontrolled conditions [12]. 3D face model provides a very good representation of the face. The problem is feature matching, computational complexity and 3D data acquisition.

Problems that occur in one group of methods may not exist in another. To ensure proper representation of the face under great variability in head rotation, lighting, expression etc. in appearance approaches many templates should be provided. 3D representation is insensitive to such factors but has own issues. In this respect, new hybrid solutions emerge. Approaches from different groups (e.g. 2D+3D) are used together [12, 13]. Numerous attempts have been made in face recognition based on the fusion of different types of data (thermal images with visible images [9, 10]). These solutions demonstrated higher performance in face recognition problem. There are also solutions where different techniques from the same group are combined in one system [7, 11, 15]. Two variants of feature combination are possible [5]: parallel and serial.

Expansion of the base structure

The base structure of an automated person identification system presented in Fig. 1 could be expanded. Basic system can be improved and some of its features can be strengthened. It is possible by the integration of additional function blocks:

- virtual face image generator,
- light compensator,
- masking block,
- face tracker,
- feature space reducer,
- pattern selector.

The above mentioned function blocks implement some expansion strategies. These strategies include:

- improvement of the face database representativeness,
- stabilization of the results,
- reduction in computational complexity,
- increase in recognition efficiency,
- increase of the capabilities of the system.

In appearance based approaches many templates should be provided to cover proper representation of the face under variations in head rotations and face expressions. It is possible to obtain many templates from a single image containing a face by zoom, tilt and pan. This task in the expanded structure of the face recognition system is performed by virtual face image generator. This block may also provide additional patterns needed in some feature extraction methods which require a correspondingly large number of reference images.

Two consecutive function blocks (light compensator and masking block) perform the task of preprocessing. The first one is responsible for illumination compensation. Some feature extraction methods are insensitive to unfavourable lighting conditions but for most approaches it is severe problem. Masking block, in turn, is responsible for appropriate selection of face region. Its main task is background removal. This block is frequently used, in holistic approaches, to focus on different regions of the face or even to assign different weights to these regions.

Another additional block – face tracker – plays significant role in stabilization of the system results. By tracking a face in a video sequence many individual identification results can be generated and in the further step aggregated. The final result may be obtained for example by voting procedure. Many weak or uncertain individual identification results may be omitted without the loss for the entire system.

Feature space reducer is the next additional block in complex system structure. Its main tasks include the reduction of feature vector and improvement in data clustering. Some feature extractor may provide more or less correlated features. By the transformation to the feature space of lower dimensionality the data redundancy can be eliminated and better clustering assured.

The last from the proposed expansion blocks is the pattern selector. Pattern selector operates only in system registration mode when users are enrolled to the database. Its task is to select those patterns which best reflects diversity of the given face. New face images of the person who is in the registration mode are added to the database if the variance to database images is above the given threshold.

The expanded structure of the face recognition system

Figure 2 presents the structure of the face recognition system with additional blocks. The structure is complex. The base elements are denoted by white and new ones by grey.

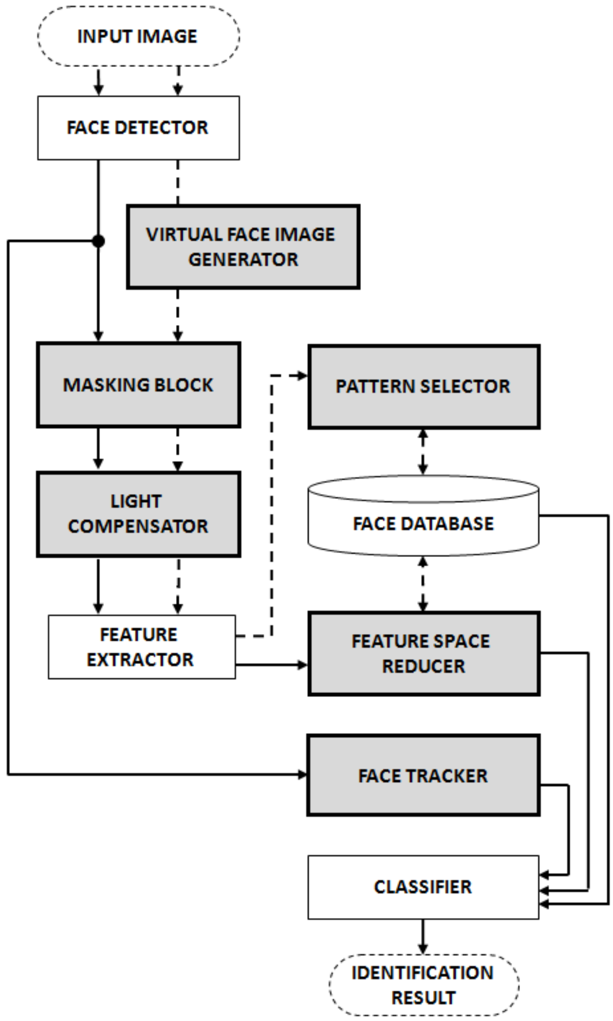

Fig.2. Expanded structure of the face recognition system

The proposed system operates in two modes:
- registration mode (dotted line),
- identification mode (regular line).

The rules of operation for each mode can be summarized in the following steps. In the registration mode there are eight steps.

Step 1: Image acquisition from a video camera.
Step 2: Face detection.
Step 3: Virtual face image generation.
Step 4: Background removal.
Step 5: Lighting compensation of the face region.
Step 6: Feature extraction.
Step 7: Feature vector rating.
Step 8: Feature space reduction.

It must be noticed that after face detection (in step 2) each detected face and generated virtual face (in step 3) images are computed in steps numbered from 4 to 7. In step 7 feature vectors are rated according to the representativeness criteria. Depending of the outcome of this procedure the feature vector is added to the face database or not. Exchange of feature vectors is possible also, i.e. new feature vector of good quality may replace the existing one in the database. After all persons are enrolled to the system, feature space reduction procedure is executed.

In identification mode also eight steps can be distinguished:

Step 1: Image acquisition from a video camera.
Step 2: Face detection.
Step 3: Background removal.
Step 4: Lighting compensation of the face region.
Step 5: Feature extraction.
Step 6: Feature vector transformation.
Step 7: Feature vector classification.
Step 8: Generation of the identification result.

In step 6 feature vectors are transformed to the feature space of lower dimensionality. After the recognition from the individual frame the results are aggregated. Face tracker data are used. In case the face was tracked and identified in previous frames the final result is generated based on individual recognitions.

Evaluation of proposed structure

In the preceding paragraphs some techniques to increase the effectiveness of the base face recognition system have been described and appropriate functional blocks distinguished. Structure of the system with new function blocks has also been proposed. It must be noticed, however, that it is not compulsory to include all blocks in any developed system. Some functional block can be omitted. For the experimentation purposes few face recognition systems based on complex structure presented in Fig. 2 will be generated. Core blocks parameters of these systems are as follows.

- Feature extractor: low-frequency components of the 2D DCT transform. These coefficients contain high energy and well describe the face image. Coefficients are selected by a triangle method (11 diagonals are used with zeroing of the first element). The reader can find more details of the method in [11].
- Classifier: Nearest neighbour based on *L2* metrics.

The parameters of additional blocks are as follows.

- Virtual face image generator: 10 virtual face images are generated from a single face image.
- Light compensator: histogram equalization.
- Masking block: square root of the Hanning window.
- Face tracker: aggregating the results on the base of the majority voting for 5 consecutive frames.
- Feature space reducer: Linear discriminant Analysis (LDA).
- Pattern selector: Far_ClassMed [16]. This method uses the distance to the average face image in the class. During the enrolment stage existing database images for a given class and new one are rearranged in such a way that farthest from the median of the calculated distances (extreme) are stored. New image is added to the database if it is sufficiently representative. Those images, having a high similarity with the existing ones, are discarded.

In order to compare the proposed solutions with contemporary developments reported in literature the ORL database of faces [17] was used. This database has been used for years and is still one of the most willingly used benchmark database today. For this reason its description is omitted here. The main benchmark performed on the ORL face database rely on equal division of face images. Half of the 400 images (5 from 10 from each class) are used as templates in learning stage other are used for testing. This variant of data division is reported in literature [1] as 5/5. Based on that division the recognition rate is calculated. Different divisions on the ORL database of faces are reported. For example 7/3 data division variant means that 7 face images are used in learning stage while remaining 3 are used during testing.

Due to the specific nature of the benchmark face database it is not possible to use the full potential of proposed structure. The ORL database of faces consists of face images. This is the reason why the face detection block is omitted completely from the system description. The potential of the generator of virtual face database cannot also be demonstrated. The same is with face tracker.

Three face recognition systems elaborated on the base of proposed structure (presented in Fig. 2) will be compared to the latest developments reported in the literature. The first system, called VIS.01 (Visitor Identification System ver.01), is the most comprehensive. In feature extractor 10 diagonals with zeroing the first elements DCT are used. Perfect recognition rate was achieved here. With the omission of additional block of pattern selector – VIS.02 system – result of 96.5% has been achieved (9 diagonals of DCT coefficients). In the last case – VIS.03 – the base structure of the system was subjected to the evaluation process with the result of 93%. The obtained results were compared with the solutions presented in the literature and are summarized in the chart presented in Fig. 3. Solutions developed on the basis of the proposed structure are denoted with the darker colour. For the cited method the original nomenclature has been preserved. All approaches are assembled from references [15, 18-24] where original solutions are proposed as well as techniques reported by other authors.

Analysing the presented comparison, it can be concluded that the proposed solutions are among the best. What is important here, the results were achieved with the changes in the structure of the system. Simple processing methods were used here and the result is comparable with intricate solutions presented in the literature.

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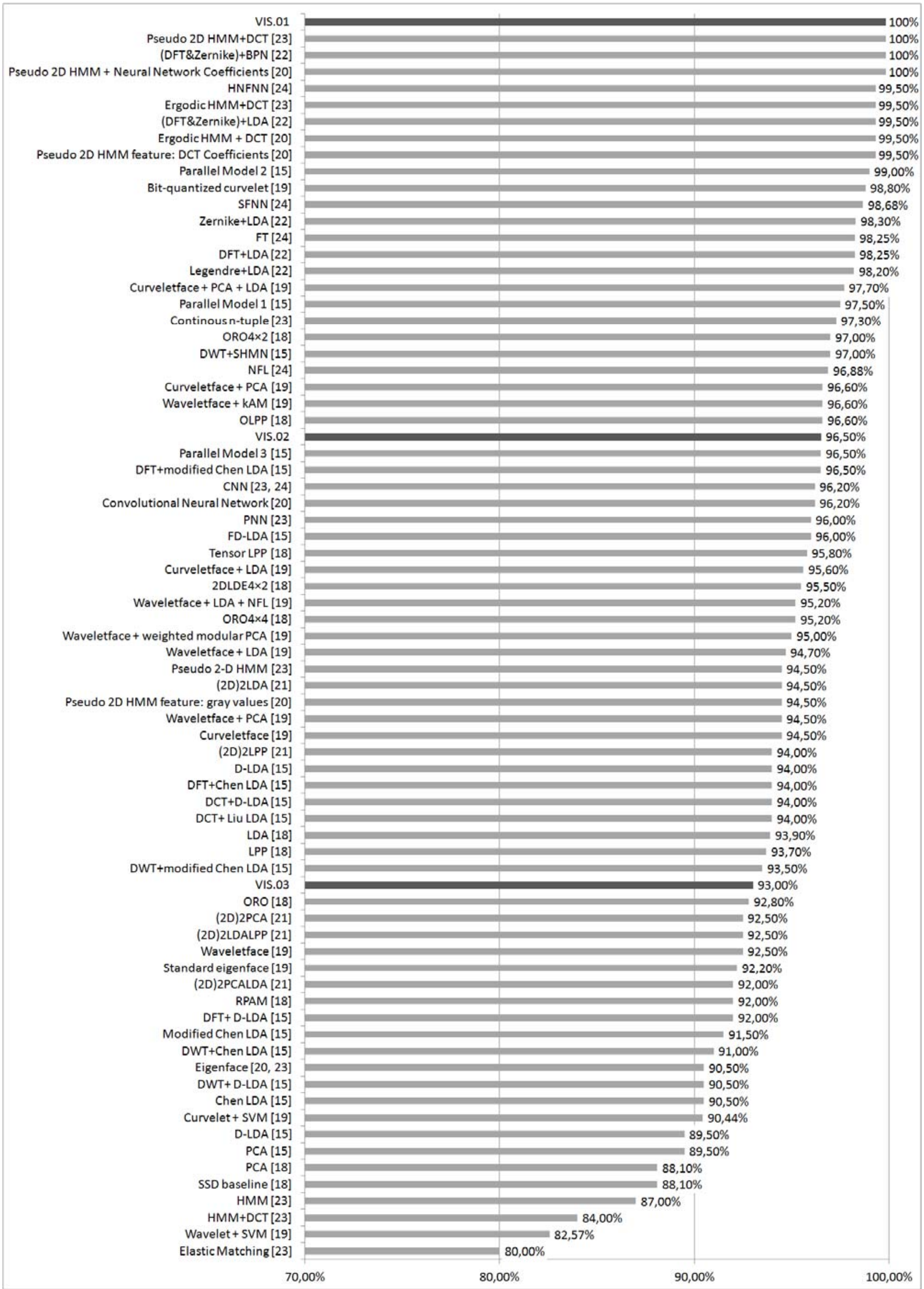

Fig.3. Comparison with the solutions presented in the literature on the ORL benchmark face database and 5/5 data division

Summary

Mechanisms for increasing the efficiency of holistic face recognition systems have been considered in the article. The base structure of the face recognition system was discussed at the beginning. It served as the foundation for system expansion. Additional function blocks have been introduced to the system structure. Without replacement in base element of the system, leaving existing blocks unchanged, only by integration of supplementary mechanisms it was possible to increase recognition rates of the system. Two prototypes made on the extended structure with different combinations of new function blocks demonstrated an increase in the efficiency compared to the prototype built on the base structure. In addition, it has been demonstrated that the proposed solutions are comparable or better with well-known literature approaches.

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