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A membrane-inspired bat algorithm to recognize faces in unconstrained scenarios

Bisan Alsalibi [a,*], Ibrahim Venkat [a], Mohammed Azmi Al-Betar [b]

[a] School of Computer Sciences, Universiti Sains Malaysia, 11800 USM, Malaysia
[b] Department of Information Technology, Al-Huson University College, Al-Balqa Applied University, Jordan

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ABSTRACT

Face recognition under unconstrained environments has become increasingly important due to the broad prospect in real-world applications. In order to counter uncertainties imposed by faces captured in such unconstrained imaging situations, a robust, discriminative and computationally efficient feature selection scheme is of paramount significance. In this regard, bio-inspired feature selection methods have been exploited due to their sophisticated ability, flexibility and adaptability. However, their performances tend to deteriorate severely in large-scale domains such as face recognition due to the premature convergence problem. In this paper, high-dimensional LBP features are extracted from face images and fused with Gabor wavelet features using Canonical Correlation Analysis (CCA). To further enhance the discrimination power of the facial representation and to alleviate the curse of dimensionality, a novel membrane-inspired feature selection approach is proposed, where a Binary Bat Algorithm (BBA) under the framework of Membrane Computing (MC) is employed. Inherent parallelism and non-determinism are two distinguishing characteristics of MC that can help in maintaining the diversity of population and balancing the exploration–exploitation trade-off. In the proposed membrane-inspired BBA (MIBBA), the structure as well as the evolution, dissolution and communication rules of MC are integrated into the BBA to enhance the trajectories of bats. Furthermore, the Great Deluge Algorithm (GDA), is integrated into the skin membrane to further improve its exploitation ability. Experimental results show that the proposed approach yields competitive recognition rates and outperforms well-known state-of-the-art methods on three benchmark databases (AR, LFW and GBU). Further experimental evaluations justify the ability of the proposed approach to handle the small sample size problem.

1. Introduction

Due to the non-intrusive nature, human analogy and universal applicability, Face Recognition (FR) has been gaining tremendous attention from the biometrics community in the last few decades. After years of progressive development, FR approaches have attained impressive results under controlled laboratory conditions. However, the recognition performance is dramatically reduced when the face images are captured under unconstrained settings or the so called ‘‘faces in the wild’’. In this context, many ingenious approaches have been formulated to enhance the robustness of unconstrained FR systems by employing complementary and over-complete feature descriptors. Over-complete representation can be obtained either by fusing different descriptors or by extracting multi-scale features from dense facial landmarks. Theoretically, with the use of large number of features, more discriminating power can be gained; however, practically, this is rarely the case (Yu and Liu, 2004). The high dimensionality would not only affect the recognition accuracy, but also can impose computational constraints. Hence, employing a feature selection is essential for eliminating redundant and irrelevant features so as to provide highly discriminating feature representation. Interestingly, bio-inspired approaches exhibit special characteristics which enable them to complement traditional FR methods. First, their adaptive nature enables the development of real time FR models. Second, bio-inspired methods have the capability of providing a robust platform to effectively recognize data which can be noisy, partially occluded, or inaccurately located. Finally, bio-inspired approaches have a massively parallel architecture that can be exploited to deal with the curse of dimensionality (Zhang and Zuo, 2007). The integration of biologically motivated algorithms in FR models has been

* Corresponding author.
E-mail address: besansalipi@gmail.com (B. Alsalibi).

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emerging owing to their intelligent problem solving ability, flexibility and scalability (Alsalibi et al., 2015; Nebti and Boukerram, 2017).

Bat Algorithm (BA) is a meta-heuristic optimization approach which takes its inspiration from the echolocation characteristics and foraging behavior of bats (Yang, 2010). Similar to other optimization techniques, BA has shown good performance in small or medium sized search problems. However, it still encounters serious problems in large scale domains (Wang et al., 2013). In such cases, the key shortcomings of BA are the risk of being trapped in local minima (premature convergence) and the slow convergence (Chen and Mahfouf, 2009; Chakri et al., 2017). In this context, striking a balance between exploration and exploitation is essential to cope with such limitations. BA algorithm mimics the echolocation behavior of bats that typically involves interaction between different bats in the swarm. In order to enhance the performance of such interactions and to improve the trajectories of bats, the structure, communication topologies and evolution rules of membrane computing will be incorporated in BA.

Membrane Computing (MC) is a fast growing area of research which takes its inspiration from the subdivisions of biological cells into compartments delimited by membranes (Paun, 2005). MC possesses several features including maximal parallelism and the locality of interactions. Recently, a promising research discipline of membrane computing, that aims at exploring the possible interactions between evolutionary computation and membrane computing, has been launched (Zhang et al., 2014b). These hybrid algorithms are known as Membrane-Inspired Evolutionary Algorithms (MIEA). MIEA exploit the concepts and principles of metaheuristic search algorithms and the hierarchical or network structures as well as the rules of membrane systems.

In this paper, two mechanisms have been proposed to improve the recognition accuracy. Firstly, uniform Local Binary Patterns (LBP) features are extracted from multi-scale image patches located at predefined facial landmarks to generate High Dimensional LBP (HDLBP) features, which in turn, are combined with Gabor features using Canonical Correlation Analysis (CCA) to empower the discriminating capability of the facial representation. Secondly, to further enhance the feature descriptor, an enhanced version of BA, called Membrane-Inspired Binary Bat Algorithm (MIBBA), is proposed to select the most discriminative and robust facial features. In MIBBA, although incorporating the structure and rules of membrane computing into the bat algorithm enhances its global search capability, empowering its intensification capability is essential to find an optimal balance between exploration and exploitation. Thus, a local search algorithm, known as Great Deluge Algorithm (GDA), is integrated into the skin membrane to improve the exploitation ability of MIBBA and to guide the convergence and diversity of populations in the elementary membranes. The parallel structure of MIBBA enables the parallel implementation of the algorithm on multiple cores, thus decreasing the computational time.

The remainder of this paper is organized as follows: Section 2 presents the related work and provides a brief overview of the standard bat algorithm and membrane systems. Section 3 describes the feature extraction and fusion phase, Section 4 illustrates the methodology of employing the MIBBA for feature selection. Section 5 presents the classification and recognition phase. In Section 6, experimental results and analysis are provided to illustrate the effectiveness and efficiency of the proposed approach. Finally, Section 7 concludes the research work presented in this paper and gives some possible future directions.

2. Background

2.1. Related work

In the aspect of how features are being extracted, FR approaches can be broadly classified into either global or local methods (Zhao et al., 2003). Generally, global methods require constructing a new subspace to represent images. Finding the appropriate subspace needs a training dataset which might be biased (Bereta et al., 2013). This might be the real motivation underlying the great interest that local methods arouse in recent years. Basically, local features are robust to some local distortions such as illumination and occlusions. This would allow the local matching techniques to achieve high recognition accuracy, even on images that were obtained in unconstrained settings (Li et al., 2013; Bereta et al., 2013; Zhou et al., 2017).

Texture is an essential characteristic that describes the physical properties of an image including roughness and smoothness (Zucker, 1976). The importance of texture-based local descriptors such as Local Binary Patterns (LBP) has been revealed in several reported works pertaining to FR. LBP has been first proposed by Ojala et al. (2002) and since then it has become one of the most widely used descriptors for FR due to its computational simplicity and invariance to different lighting conditions. LBP has been used in face authentication and verification (Ahonen et al., 2004; Zhang et al., 2005), face detection (Jin et al., 2004) and face localization (Huang et al., 2004). Although LBP is relatively insensitive to monotonic gray-level changes, its main limitation is the sensitivity to noisy pixels wherein the value of the pixels can be easily affected by the erroneous surrounding pixels (Guo et al., 2010; Bereta et al., 2013). Further improvements on the original LBP have been proposed to tackle this limitation; for instance, circular, uniform and improved LBP (Ahonen et al., 2004; Jin et al., 2004).

Chen et al. (2013) empirically demonstrated that specific high-dimensional features are significant for obtaining high performance. In their work, two mechanisms had been employed to increase the dimensionality of the features namely, dense landmarks and multiple scales. Specifically, uniform LBP had been extracted from up to five scales around 27 facial landmarks. From each landmark, a total of 16 blocks of size 10×10 pixels were used to compute uniform LBP histograms. Motivated by this strategy, Zhang et al. (2015) proposed a similar feature extraction method using the Weber Local Descriptor (WLD). Local features are being extracted using WLD from multi-scale image patches that are centered at dense facial landmarks. After that, fusion of features is performed by randomly selecting parts of the extracted local features. However, the use of multi-scale or fused descriptors tend to generate high dimensional feature vectors. The high dimensionality could be solved by integrating an appropriate feature selection mechanism to select the optimal subset of features rather than generating new features. Feature selection has been extensively applied in many practical applications such as text processing, face recognition, bioinformatics and data mining, to name a few (Lee, 2015; Moradi and Rostami, 2015; Hu et al., 2015; Gheyas and Smith, 2010). The main objective of the feature selection approaches is to remove redundant and irrelevant features; consequently, providing a better classification accuracy and less computational time. Feature selection mechanisms can be classified into two categories, namely filter-based and wrapper-based. Filter-based methods exploit statistical and intrinsic characteristics of data to independently select optimal subset of features based on the correlation and relationships within features (Unler et al., 2011). On the other hand, a learning algorithm and a classifier are utilized to determine the goodness of the selected features in wrapper-based approaches (Kohavi and John, 1997).

Practically, in a high dimensional space, an exhaustive exact search for the optimal subset of features is computationally more costly (Yu and Liu, 2004). A recent trend in the literature is to formulate the problem of feature selection as a multi-objective combinatorial optimization problem, where the objective functions are the accuracy of the classifier and the cardinality of the feature set.

2.1.1. Bio-inspired face recognition algorithms

In the FR domain, various bio-inspired approaches have been used either to optimize the extracted feature descriptors, the selected facial landmarks or to tune the parameters of algorithms as emphasized in (Liu and Wechsler, 2000; Zheng et al., 2005; Panda et al., 2011; Chakrabarty et al., 2013; Panda and Naik, 2015). For instance, a binary Gravitational Search Algorithm (GSA) with dynamic adaptive inertia