摘 要

人脸识别技术作为一种被广泛接受的生物特征识别技术，具有重要的理论价值和广阔的应用前景。经过几十年的发展，人脸识别技术取得了长足的进展。大量的性能评测与学术研究表明，在可控测试条件下，最好的人脸识别技术已经能够取得令人满意的性能指标；然而，在非可控条件下，光照、表情、姿态及其他因素等引起的变化导致了同类样本之间的差异甚至要大于不同类别样本之间的差异，这极大地影响了人脸识别算法的性能。

特征表示作为人脸识别算法的关键所在，受到了极大的关注。本文从全局和局部两个角度综述了人脸识别中常用的特征表示方法。局部特征对光照、表情、部分遮挡等产生的变化具有较好的鲁棒性，因而在人脸识别中受到了广泛的关注。Gabor 小波表示作为一种有效的局部特征，在人脸识别上取得了良好的效果。为了发掘 Gabor 特征在人脸识别中的潜力，本文研究了人脸图像 Gabor 特征的局部模式表示方法，并进一步研究了其与判别性特征提取相结合的方法。本文所取得的主要研究成果概述如下：

1. 提出了融合 Gabor 幅值和相位局部模式的表示方法。

Gabor 相位特征对图像位置的变化非常敏感，这导致大多数利用相位特征的表示方法在人脸识别中取得了非常低的分类精度。针对这一问题，文中提出了基于相位特征的局部 Gabor 异或模式表示。该表示先将图像的 Gabor 相位特征量化到不同的区间，然后利用异或算子来计算空间邻域内像素的局部模式，并采用分块的直方图来表示图像。其优点在于，采用的量化策略减弱了模式受相位对图像位置变化敏感性的影响，而多尺度、多方向上的直方图特征具有很强的表示能力。为了利用 Gabor 幅值和相位特征之间的互补性，文中采用判别性特征提取方法在块级别上对幅值和相位的局部模式表示进行融合，并通过和规则融合图像块之间的相似度。该方法从 Gabor 特征的局部模式表示中提取了低维的判别特征，不仅减少了图像相似度的计算代价，而且提高了识别精度。此外，局部 Gabor 异或模式是一种有效的基于相位特征的表示，保证了其与幅值局部模式融合的方法能够取得更优的识别性能。

2. 提出了 Gabor 特征“体”局部模式的表示方法。

为了高效地建模人脸图像 Gabor 特征的局部模式，该方法将多尺度、多方向的 Gabor 特征组织为一个三维“体”：该 Gabor 特征“体”的前两维是图像平面，第三维对应了不同尺度、不同方向上的 Gabor 小波。然后，该方法采用了局部二值模式算子来计算幅值特征“体”上的局部模式，并利用直方图来表示人脸图像。该模式表示组合了图像平面内的模式与同一点不同滤波器响应上的模式，因而具有更强的表示能力。文中进一步提出了该表示的两种扩展：利用 Fisher 准则的子块权重学习与判别性特征提取。子块权重学习方法利用 Fisher 准则基于训练集学习得到各个子块的权重，并根据这些权重来融合

图像上不同子块之间的相似度。该方法利用了人脸不同区域的判别能力，在训练集与测试集中图像的变化类型保持一致时能够提高识别的性能。判别性特征提取方法根据 Fisher 线性判别分析从图像块级别上提取低维特征并计算图像块之间相似度，然后通过和规则融合这些相似度。该方法提取了有利于分类的投影方向，在测试的三个人脸数据库上都表现出了更优的分类性能。

3. 提出了基于学习的局部 Gabor 模式表示方法。

从人脸图像的构成来看，在图像像素与人脸部件之间存在一种中间的表示，称为“模式”。人脸作为一类结构非常相似的物体，应当有其专属的模式构成。从这一角度出发，针对某个尺度、某个方向的 Gabor 小波，该方法从人脸图像的 Gabor 特征上采样得到图像块的集合，进而学习得到对应的码本：该码本中的每个码字对应了一种模式；然后，根据学习得到的码本去表示人脸图像。考虑到人脸的不同区域和不同模式在识别过程中的不同作用，文中进一步提出了利用子块和模式权重的加权方法。此外，针对文献中存在的 11 种 Gabor 特征的局部模式表示方法，文中按照模式的定义将它们划分为两大类：模式设计方法和模式学习方法，并从模式定义流程以及方法参数两个方面对这些方法进行对比分析。由于这些表示具有高维的特征，文中采用了判别性特征提取的方法来提取低维的特征。大量的实验结果表明，基于学习的局部 Gabor 模式表示方法是一种有效的人脸表示，特别地，该方法受不同训练集上产生码本的影响比较小；加权方法同时利用了子块和模式的区分能力，进一步提高了识别精度；该模式表示与判别性特征提取结合的方法提取了判别特征，取得了比基准方法和加权方法更高的识别性能。

综上所述，本文围绕人脸图像的 Gabor 特征从模式表示的角度展开了相关的研究，提出了三种局部 Gabor 模式表示方法。此外，本文研究了判别性特征提取的方法并将其与不同的局部 Gabor 模式表示结合，不仅降低了局部 Gabor 模式方法中相似度计算的代价，而且在很多富有挑战性的人脸数据库上取得了优异的效果。

关键词：人脸识别；局部特征；Gabor 特征；局部二值模式；模式学习；判别分析

Study on Local Feature for Face Recognition

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Face recognition technology is regarded as one kind of widely accepted biometric identification technology, and has both significant theoretical values and wide potential applications. In the past few decades, much progress has been made in face recognition. Many performance evaluations and academic research results show that the best face recognition algorithm has achieved the desirable performances under controlled testing conditions. However, due to the variations arising from lighting, expression, pose and other factors under uncontrolled conditions, the intra-personal variations might be even larger than inter-personal variations. This greatly degrades the performances of most face recognition algorithms.

Face representation is generally regarded as the key to one face recognition algorithm, and has received much attention. This thesis reviews the widely used face representation methods for face recognition from both global and local aspects. Local feature is robust to the variations due to illumination, expression, partial occlusion and other factors, thus attracts much attention in face recognition. As one kind of effective local feature, Gabor wavelet representation has achieved good face recognition performances. To seek the potential of Gabor features for face recognition, this thesis studies the representation methods using local patterns of Gabor features, and further investigates their combinations with discrimiantive feature extraction method. The main contributions of this thesis are as follows:

1. Propose a representation method fusing local patterns of Gabor magnitude and phase features.

Gabor phase features are very sensitive to the varying image positions, and this leads to that most face representation methods using phase features generally achieve the low face recognition accuracies. Aiming to this question, local Gabor XOR patterns (LGXP) based on phase is proposed. This descriptor quantizes phase into different ranges, then calculates the pattern of pixels in spatial neighborhood by using XOR operator and utilizes block-based histogram to represent face images. Its merit lies in that the quantization strategy makes patterns less affected by the sensitivity of phase to the varying image positions, and multi-scale and multi-orientation histogram features have better representation power. To utilize the complementary information of Gabor magnitude and phase features, the discriminative feature extraction method is adopted to fuse local patterns of magnitude and phase at the image block level, and

all the block-level similarities are fused together according to the sum rule. The proposed method derives the low dimensional discriminative features from local patterns of Gabor features, and it not only reduces the cost of calculating similarity between images but also improves the face recognition accuracies greatly. In addition, LGXP descriptor is one effective representation based on Gabor phase features, and this ensures that its fusion with local patterns of Gabor magnitude features could achieve the better performances.

2. Propose one representation method based on local patterns of Gabor "volume" features.

In order to effectively model the patterns of Gabor features, multi-scale and multi-orientation Gabor features are organized as one three-dimensional "volume": its first two dimensions are image spatial domain and the third dimension corresponds to Gabor filters at different scales and orientations. Then, Local Binary Patterns (LBP) operator is adopted to calculate the pattern in Gabor magnitude "volume" features and histogram is utilized to represent face images. This descriptor combines the patterns in both image spatial domain and different filter responses at the same position, thus has better representation power. Two extensions of this descriptor are further presented: weights learning for subblocks using Fisher's Linear Discriminant analysis (FLD) criterion and discriminative feature extraction method. The subblock-weights learning method utilizes FLD criterion to learn the weights of different subblocks from one training set, and fuses the subblock-level similarities by using the learned weights. This method adopts the discriminative abilities of different facial regions, and could improve the face recognition performances when the variations of images in probe set are basically the same as those in training set. The discriminative feature extraction method applies FLD to the image block-level representation to derive the low dimensional features and calculates the block-level similarities, then fuses these similarities according to the sum rule. This method derives the desirable projections for classification tasks, and improves the results on the three testing face databases.

3. Propose learned local Gabor patterns for face representation.

According to the image hierarchical structure, one middle level exists between image pixels and facial components, and is denoted as "pattern". As one kind of objects with the similar structures, faces should have the specific pattern elements. From this viewpoint, for Gabor wavelet at certain scale and orientation, this method constucts one patch set by sampling patches from Gabor filtered face images, and learns one corresponding codebook: its each codeword corresponds to one kind of

pattern; then, this method represents each face image based on the learned codebooks. Considering that different face regions and different patterns have different discriminative abilities, the weighted method by using the weights of both subblocks and patterns is further proposed. Additionally, aiming at all the 11 methods using local patterns of Gabor features in the literatures, this thesis classifies them into pattern-designed and pattern-learned methods according to their pattern definitions, and makes a comparison between them from two aspects: pattern-definition flowcharts and parameters. Due to the high dimensional feature of these descriptors, this thesis adopts the discriminative feature extraction method to derive the low dimensional features. Extensive experimental results show: 1) that the representation method using learned local Gabor patterns is effective for face recognition and, in particular, it is less affected by the codebooks learned from different training sets; 2) that the weighted method utilizes the discriminative ability of both subblocks and patterns, further improves face recognition rates; 3) that the method comibining learned local Gabor patterns and discriminative feature extraction derives the low dimensional discriminative features, and performs better than both the baseline method and the weighted one .

In summary, this thesis studies the face representation methods using local patterns of Gabor features, and proposes three kinds of methods using local Gabor patterns. In addition, this thesis investigates the discriminative feature extraction method and combines it with different local Gabor patterns. The combination method not only reduces the cost of calculating similarity in the methods using local Gabor patterns, but also achieves the excellent results on the challenging face databases.

Keywords: Face recognition; Local feature; Gabor features; Local binary patterns (LBP); Pattern-learning; Discriminant analysis