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人脸老化的统计建模及其有效性评价

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摘 要

人脸老化是人脸表观随时间推移呈现的一种非人为控制的、必然的、不可逆转的缓慢变化，对人脸老化的建模是人脸相关研究的一个重要方面，吸引了来自计算机视觉、图形学、心理学等领域的广泛关注。人脸老化建模旨在理解人脸在老化过程中发生的变化，发掘其内在的规律性，并建立相应的数学模型。一方面，人脸老化建模可以促进人类学、人体测量学、遗传学等学科发展，具有深刻的理论意义；另一方面，一个科学的老化模型不仅可以预测人脸老化轨迹，还可以指导年龄估计算法的设计、帮助长时间跨度的人脸识别等，在现实生活中具有广阔的应用前景，如寻找丢失儿童或长期潜逃的通缉犯、进行特技合成、开发特定年龄段用户的检索系统等。然而，由于人脸老化的一些独特属性，比如机理复杂、训练样本收集困难且数据纯度低、存在多样性和不确定性、缺乏定量的模型评价方法等，对人脸老化建模的研究面临着诸多挑战。

本文在人脸老化的建模和老化模型的有效性评价两方面进行了一系列的研究，完成了以下几方面的工作：

1. 提出了一种基于分解式人脸表示的老化建模框架，即局部马尔可夫老化模型。

针对人脸老化建模面临的几个挑战，包括变化繁多复杂、高度非线性、具有多样性和不确定性、训练样本缺乏等，该老化建模框架采取了以下学习策略：在空间域将人脸分解成一系列子区域，既而对其老化过程分别进行建模；在时间域将整个老化过程离散化，逐年龄段学习人脸的老化模式；采用概率采样技术模拟老化过程的多样性。该建模框架很大程度上降低了模型复杂度和对训练样本需求，是一种有效的老化建模方法。

2. 提出了一种人脸老化模型有效性的间接评价方法。

本文首先分析人脸老化过程呈现的规律性，并据此定义了两条老化模型的间接评价准则，即年龄感知精确度准则和身份保留准则；然后从这两条准则出发，结合主客观评价实验的特点提出了一套评价实验的设计方案；最后采用统计分析方法对实验结果进行定量分析，提出一个度量模型有效性的指标。同时，文中还提出了一种基于层次式人脸表示进行特征设计的人脸年龄估计方法，用于年龄感知精确度准则下的老化模型评价。

3. 提出了一种基于与或图的种群相关的人脸老化模型。

在局部老化模型的框架下，该模型将老化过程形式化为一系列层次式高分辨率人脸表示（与或图）构成的马尔可夫链，并利用同一地域的人脸在局部表观和老化模式上的相似性，从“不同年龄段的相似人脸”代替“同一个人不同年龄段的人脸”学习马尔可夫链的动态参数。在三个不同种族的数据库学得的人脸老化模型在老化模拟实验和模型定量评价实验中都表现出了良好的性能。

4. 提出了一种从局部稠密的老化数据库学习长期老化模式的人脸老化模型。

该老化模型也是在局部马尔可夫老化模型框架下的一种实现。对于分解式人脸表示，该模型提出了面向老化的分解式主动表观模型（Active Appearance Model，简称 AAM）[Cootes'01]；对于动态模型的学习，该模型基于长期老化过程的平滑性和马尔可夫性，通过“串接趋势近似的短期老化模式”的方式从局部稠密的数据库中学习长期人脸老化模式。在多个群体上的老化模拟实验和对模型的定量评价实验均验证了该老化模型的有效性。

以上研究内容表明：局部马尔可夫老化模型是对人脸老化过程建模的一条可行的研究思路，在现有的模型评价准则下能够合理地模拟人脸老化过程；本文提出的人脸老化模型间接评价方法可以为老化模型的有效性提供科学的量化指标，并指导老化建模的发展方向。本文的研究对人脸老化的学习有很大的推动作用，为进一步的研究奠定了基础。

关键词：人脸老化建模；马尔可夫；与或图；多样性；有效性评价；方差分析。

Studies on statistical face aging modeling and its evaluation

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Aging is an uncontrollable, inevitable and irreversible slow process occurring on all human faces as time elapses, thus face aging modeling is one of the most important studies on human faces and attracts research interest from computer vision, graphics and psychology, et al. The target of aging modeling is to understand the various aging-related variations on face appearances, discover the intrinsic laws and describe them using mathematical models. On the one hand, modeling of face aging process can promote the progresses in anthropology, genetics and other related fields, thus is of great theoretical value; On the other hand, a good face aging model can predict aging related appearance changes, propose age estimation algorithms and help develop aging robust face recognition systems, so face aging modeling is a field with wide application foreground, e.g., looking for missing children and wanted fugitives, generating special effects in filmmaking, developing age-specific retrieval systems, et al. However, face aging modeling encounters multiple challenges due to its intrinsic characteristics, e.g., the aging mechanism is highly complex, collection of aging databases is time consuming and the collected data are usually affected by non-age related variations, face aging is intrinsically uncertain and diverse, there lacks of a quantitative evaluation approach for aging models, et al.

This thesis studies both statistical face aging modeling and aging model evaluation, and the main research achievements are summarized as follows:

1. Proposes a face aging modeling framework based on compositional face representation: local Markov aging model.

To cope with the multiple challenges of face aging modeling, e.g. various appearance changes, highly nonlinearity, intrinsic diversity and uncertainty, lacking of sufficient training data, etc., the proposed framework adopts following strategies: firstly, decompose a face into sub-regions under specific constraints and simulate the aging process of each region separately; secondly, discretize the age range into short spans and model the aging process sequentially; thirdly, adopt probabilistic sampling methods over the Markov process to simulate the uncertainty. All of these strategies help to reduce the complexity of aging modeling and alleviate the demands of large training dataset, thus make the framework effective.

2. Proposes an indirect evaluation approach for the goodness of the face aging model.

Considering the intrinsic uncertainty of face aging, the thesis firstly adopts two criteria for indirect face aging model evaluation: the accuracy of age perception and the preservation of facial identity. Then, based on these two criteria, the thesis discusses the pros and cons of subjective and objective evaluations, and designs a series of evaluation experiments. Finally, a quantitative measurement is proposed to evaluate the validness of aging model. In addition, the thesis proposes an age estimation algorithm developed on a hierarchical face representation for objective aging model evaluation in terms of the accuracy of age perception.

3. Proposes a face aging model based on the And-Or graph representation and Markov graph chain.

Under the framework of local Markov aging model, this model formulates aging process as a Markov Chain on a series of hierarchical high resolution face representations (And-Or graph). Making use of the similarity existing in local appearances and aging patterns of subjects from a specific group, the algorithm selects "similar patches across adjacent age groups" instead of the "aging sequences of the same person" to learn the dynamics of the Markov graph chain. The aging models learned from three datasets of different ethnic groups perform well in both the aging simulation experiment and quantitative model evaluation.

4. Proposes a modeling approach of learning long term face aging patterns from partially dense aging databases.

The proposed approach is also built under the framework of local Markov aging model: as for the compositional face representation, the model proposes an aging-specific compositional Active Appearance Model(AAM); as for the dynamics of Markov process, this model learns long term face aging patterns by concatenating similar short term aging patterns sequentially based on the Markov property and smoothness of aging process. The effectiveness of the face aging models is validated by both the simulation results and quantitative evaluation experiments on different groups.

The above studies demonstrate that: local Markov aging model is a feasible modeling approach and is able to simulate aging process effectively under current evaluation criteria；the proposed indirect model evaluation approach provides a reasonable quantitative measurement for the validness of aging model and guides the direction of face aging modeling. The studies in the thesis promote the aging related studies and provide a basis for further researches.

Keywords: face aging modeling, Markov, And-Or graph, diversity/uncertainty, aging model evaluation, ANOVA