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Age Synthesis and Assessment via Face Recognition

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Abstract

One of the challenges in automatic face recognition is to achieve temporal invariance. In other words, the goal is to come up with a representation and matching scheme that is robust to changes due to facial aging. Facial aging is a complex process that affects both the 3D shape of the face and its texture (e.g., wrinkles). These shape and texture changes degrade the performance of automatic face recognition systems. However, facial aging has not received substantial attention compared to other facial variations due to pose, lighting, and expression. Age estimation is defined to label a face image automatically with the exact age (year) or the age group (year range) of the individual face. Because of their particularity and complexity, both problems are attractive yet challenging to computer-based application system designers. Large efforts from both academia and industry have been devoted in the last a few decades. In this paper, we survey the complete state-of-the-art techniques in the face image-based age synthesis and assessment topics. Existing models, popular algorithms, system performances, technical difficulties, popular face aging databases, evaluation protocols, and promising future directions are also provided with systematic discussions.

1. Introduction

Face recognition accuracy is usually limited by large interclass variations caused by factors such as pose, lighting, expression, and age. Therefore, most of the current work on face recognition is focused on compensating for the variations that degrade face recognition performance. However, facial aging has not received adequate attention compared with other sources of variations such as pose, lighting, and expression. As a “window to the soul”, the human face conveys important perceptible information related to individual traits. The human traits displayed by facial attributes, such as personal identity, facial expression, gender, age, ethnic origin and pose, have attracted much attention in the last several decades from both industry and academia since face image processing techniques yield extensive applications in graphics and computer vision fields.

There are two fundamental problems inspiring the development of these techniques. Face image synthesis: Render face images with customized single or mixed facial attributes (identity, expression, gender, age, ethnicity, pose, etc.). Face image analysis: Interpret face images in terms of facial attributes (identity, expression, gender, age, ethnicity, pose, etc.). Among them, face image-based age synthesis and estimation have become particularly interesting topics in recent years because of their emerging new applications. People have the ability, developed early in life, to determine age between 20 and 60 years and conceive aging appearance from the face with high accuracy, on average, with a group decision. For example, we can easily figure out the aging process on Albert Einstein’s faces, as shown in Fig. 1. Especially, the forensic artist can imagine and make realistic age progression pictures in terms of photos or Semantic description of given faces. Well-trained Swedish alcohol salespeople have professional skills for accurate age estimation with low bias. Age of face has also been considered as an important semantic or contextual cue in social networks [2], [10]. Can a machine perform the same as a human? Technology advances in computer science and engineering have given a positive answer to this question. There are two basic tasks in this field, computer-based age synthesis and assessment.

A. **Age Synthesis:** Retender a face image aesthetically with natural aging and rejuvenating effects on the individual face.
B. **Age Estimation:** Label a face image automatically with the exact age (year) or the age group (year range) of the individual face. To further understand the tasks, we want to differentiate four concepts about human age in the paper.
C. **Actual Age:** The real age (cumulated years after birth) of an individual.
D. **Appearance Age:** The age information shown on the visual appearance.
E. **Perceived Age:** The individual age gauged by human subjects from the visual appearance.
F. **Estimated age:** The individual age recognized by machine from the visual appearance.

The appearance age is typically consistent with the actual age. However, the variation is often inevitable due to the generic difference between different individuals and environmental/ artificial factors. Both perceived age and estimated age are defined on the appearance age. The actual age is often defined as the ground truth.

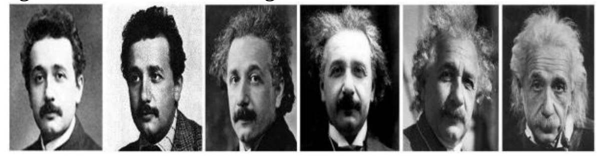

Fig: 1. Albert Einstein’s Face Aging (Collected by Internet Image Search)

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2. Real-World Applications

There are many popular real-world applications related to age synthesis [4] and estimation. Computer-aided age synthesis significantly relieves the burden of tedious manual work while at the same time providing more photorealistic effects and high-quality pictures. Age estimation by machine is useful in applications where we don't need to specifically identify the individual, such as a government employee, but want to know his or her age.

2.1 Forensic Art

The forensic art involves interdisciplinary knowledge of anthropometry, psychology, postmortem reconstruction, human aging, perception, and computer graphics. As a principal artistic technique in forensic art, age progression is used to modify and enhance photographs by computer or manually (with professional hand drawing skills) for the purpose of suspect/victim and lost person identification with law enforcement [8], [7]. This technique has evolved when police investigative work and art united throughout history. When the photos of missing family members (especially children [11], [12], [13]) or wanted fugitives are outdated, forensic artists can predict the natural aging of the subject faces and produce updated face images, utilizing all available individual information, such as facial attributes, lifestyle, occupation, and genetics.

2.2 Electronic Customer Relationship Management (ECRM)

The ECRM [14] is a management strategy to use information technology and multimedia interaction tools for effectively managing differentiated relationships with all customers and communicating with them individually. Since different groups of customers have very different consuming habits, preferences, responsiveness, and expectation to marketing, companies can gain more profits by acknowledging this fact, responding directly to all customers' specific needs, and providing customized products or services.

The most challenging part hereby is to obtain and analyze enough personal information from all customer groups, which needs companies to establish long-term customer relationships and sustain a large amount of cost input. For example, a fast food shop owner might want to know what percentage of each age group prefers and purchases what kind of sandwiches; the advertisers want to target specific audiences (potential customers) for specific advertisements in terms of age groups; a mobile phone company wants to know which age group is more interested in their new product models showing in a public kiosk; a store display might show a business suit as an adult walks by or jeans as a teenager walks by. Obviously, it is almost impossible to realize those due to privacy issues.

2.3 Security Control and Surveillance Monitoring

Security control and surveillance monitoring issues are more and more crucial in our everyday life, especially when advanced technologies and explosive information become common to access and possess [15]. With the input of a monitoring camera, an age estimation system can warn or stop underage drinkers from entering bars or wine shops; prevent minors from purchasing tobacco products from vending machines; refuse the aged when he/she wants to try a roller coaster in an amusement park; and deny children access to adult Web sites or restricted movies [16], [17]. In Japan, police found that a particular age group is more apt to money transfer fraud on ATMs, in which age estimation from surveillance monitoring can play an important role. Age estimation software can also be used in health care systems, such as robotic nurse and intelligent intensive care unit, for customized services.

2.4 Biometrics

Age estimation is a type of soft biometrics [18] that provides ancillary information of the users' identity information. It can be used to complement the primary biometric features, such as face, fingerprint, iris, and hand geometry, to improve the performance of a primary (hard) biometrics system.

2.5 Entertainment

Aging and rejuvenating are popular special visual effects in film making, especially for science fiction films such as "The Curious Case of Benjamin Button" (2008). Without any noticeable artifacts in many such movies, the actor's appearance can be transformed from young to old or reverse instantly or gradually with extremely realistic aging effects. Some of these mysterious visual effects are generated by age synthesis techniques to provide fantastic experiences to audiences. Image morphing is often used to generate a seamless transition for animation purpose, such as Michael Jackson's music video "Black or White" (1991).

3. Problems and Motivations

Although, as aforementioned, the real-world applications are very rich and attractive, existing facts and attitudes from the perception field reveal the difficulties and challenges of automatic age synthesis and estimation by computer. Different people have different rates of the aging process, [16], which is determined by not only the person's genes but also many other factors, such as health condition, living style, working environment, and sociality.

4. Effects of Different Cropping Methods

We study the performance of the face recognition system with different face cropping methods. An illustration of the cropping results obtained by different approaches is shown in Fig. 2.

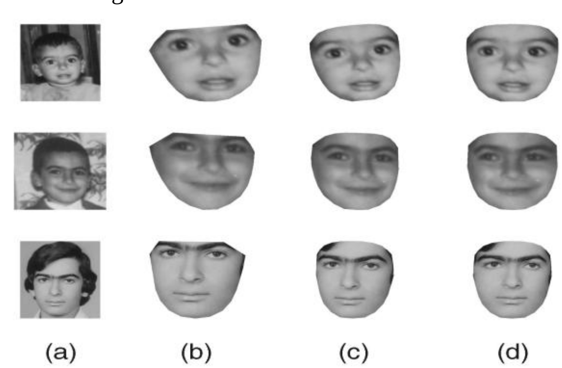

Fig: 2. Example Images Showing Different Face Cropping Methods: (a) Original, (b) No-Forehead and No Pose Correction, (c) No Pose Correction with Forehead, (d) Pose Correction with Forehead

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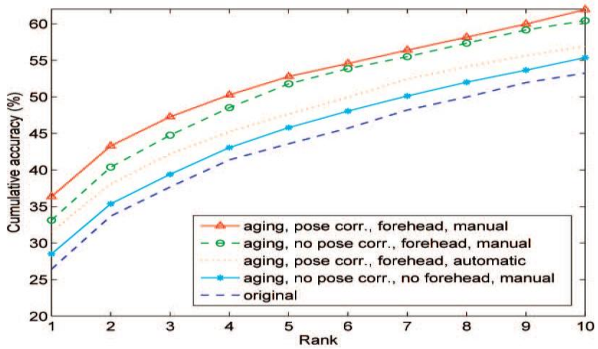
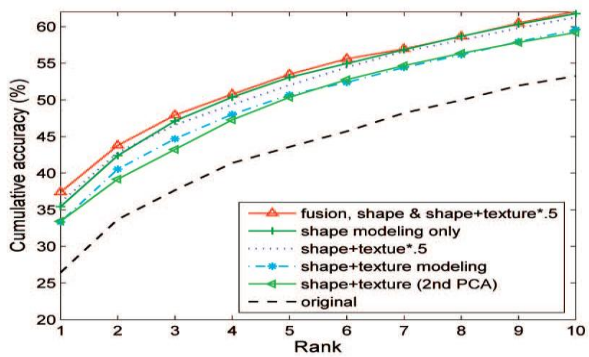
The first column shows the input face image and the second column shows the cropped face obtained using the 68 feature points provided in the FG-NET database, without pose correction. The third column shows the cropped face obtained with the additional 13 points (total 81 feature points) for forehead inclusion, without any pose correction.



(a)



(b)

Fig: 3. Cumulative Match Characteristic (CMC) Curves with Different Methods of Face Cropping and Shape and Texture Modeling. (a) CMC with Different Methods of Face Cropping. (b) CMC with Different Methods of Shape and Texture Modeling

4.1 Effects of Different Strategies in Employing and Texture

Most of the existing face aging modeling techniques use either only shape or a combination of shape and texture [3], [4], [5], [6], [7]. We have tested our aging model with shape only, separate shape and texture, and combined shape and texture modeling. In our test of the combined scheme, the shape and the texture are concatenated and a second stage of principle component analysis is applied to remove the possible correlation between shape and texture as in the AAM face modeling technique. Fig. 3b shows the face recognition performance of different approaches to shape and texture modeling.

4.2 Effects of Different Filling Methods in Model

Construction we tried a few different methods of filling missing values in aging pattern space construction (see Section A): linear, v-RBF, and RBF. The rank-one accuracies are obtained as 36.12 percent, 35.19 percent, and 36.35 percent in shape + texture 0:5 modeling method for linear, v-RBF, and RBF methods, respectively.

5. Human Aging on Faces

Human face aging is generally a slow and irreversible process, even though some retinoid (e.g., tretinoin) may

1. IEEE International Conference on Biometrics: Theory, Applications and Systems (http://www.cse.nd.edu/BTAS_08/).
2. IEEE conference series on Automatic Face and Gesture Recognition (http://www.fg2008.nl/content/specialsessions).
3. Video Mining Corporation, http://www.videomining.com/.
4. NEC Laboratories America, Inc., http://www.nec-labs.com/.

Slightly reverse minor photo aging effects.5 although people are aging differently and aging shows different forms in different ages, there are still some general changes and resemblances we can always describe, [1].

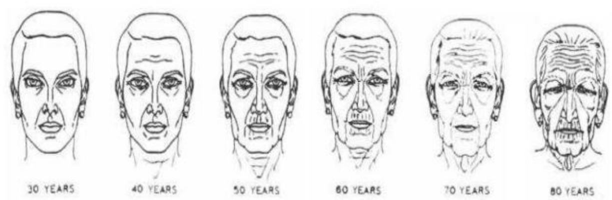


Fig: 4. Face Aging Sketches from 30 to 80 Years with 10 Years Per Sketch

Fig: 4 shows six face aging sketches from 30 to 80 years, with 10 years per sketch. Biologically [16], [5], as the face matures and ages with loss of collagen beneath skin as well as gravity effects, the skin becomes thinner, darker, less elastic, and more leathery. A dynamic wrinkles and blemishes due to biologic aging gradually appear. Dynamic wrinkles and folds due to muscle motion become more distinct. In the areas of deeper attachment, such as cheeks, eyelids chin, and nose, elasticity of muscles and soft tissues gets weak and fat continues depositing.

6. Age Synthesis on Faces

6.1 Face Modeling

Age synthesis, also called age progression, is often implemented by first building a generic face model. Face modeling has been prevalent for a long time in both the computer graphics and computer vision fields. The pioneering research of computer-generated face model can be traced back to Parke's work in 1972. A 3D mesh model is built to generate cartoon faces. Facial expression animation is synthesized by analyzing a typical pair of real face photographs. Thereafter, a large number of faces models— 3D or 2D, photorealistic, or non-photorealistic—have been developed and reported for different purposes of applications.

6.2 Geometry-Based Model

This kind of model generates automatic facial animations with generic geometric mesh, dynamic skin-muscle deformation, active contours, or anthropometric growth. They are mainly designed for non-photorealistic rendering. It digitizes facial mesh through geometric units representing face muscles, tissues, and skin in either 2D or 3D.

6.3 Image-Based Model

Image-based models focus on generating photorealistic face images from other images rather than from geometric primitives. A heuristic technique is to generate texture details on the given face images to simulate human traits, e.g., face skin retendering with creases and aging wrinkles [20]. This technique is simple to implement but too empirical to be generalized for photorealistic rendering.

6.4 Appearance-Based Model

Appearance-based models consider both shape and texture rendering to achieve highly realistic results. The shape and ***texture*** are both vectorized for image representation. Instead of heavily using empiricalknowledge like the previous two models, this kind of model usually uses statistical learning to build the model.

7. Age Synthesis Algorithms

Based on different face models, age synthesis algorithms can be applied to retender a face image aesthetically with natural aging and rejuvenating effects. Three popular synthesis algorithms are discussed as follows.

7.1 Explicit Data-Driven Synthesis

Based on the particular face model, shape, texture, or appearance can be synthesized effectively. The explicit data-driven synthesis focuses on the shape analysis, which is more related to craniofacial growth in age progression [19]. As skin textures do not change too much for young faces, the distinct shape changes during craniofacial growth are more prone to be observed and modeled for the purposes of appearance prediction and face recognition/ verification across age progression.

7.2 Explicit Mechanical Synthesis

The explicit mechanical synthesis focuses on the texture analysis, which is more related to skin aging, the most distinct facial changes after adulthood. During skin aging, wrinkles emerge and become more pronounced due to the nature of skin and muscle contraction. This technique is usually developed using image-based rendering for the purpose of photorealistic appearance prediction across age progression.

7.3 Implicit Statistical Synthesis

The implicit statistical synthesis focuses on the appearance analysis, which considers shape and texture synthesis simultaneously and often uses statistical methods. This needs to collect a database that contains a large number of face images with a broad range of ages. In this case, each face image is considered as a high-dimensional point in the age space.

So, the age synthesis can be animated by tuning the distances between faces with different ages or the model parameters controlling different appearance variations

8. Conclusions

We have presented a complete survey of the state-of-the art techniques for age synthesis and estimation via face images, which became fairly particular in recent decades because of their promising real-world applications in several emerging fields. The explosively comprehensive efforts from both academia and industry have been devoted recently to models and algorithms designing, face aging databases collecting, and system performances evaluation with valid protocols. Variant solutions to technical difficulties have also been provided by researchers. Table 1 summarizes the facts and characteristics versus countermeasures of age synthesis and estimation tasks. The N/A in the table can indicate possible future directions to mitigate difficulties or degrading factors in age synthesis and estimation. In general, different age synthesis and estimation techniques and algorithms can be effectively applied to particular scenarios or applications.

Table: 1. Facts/Characteristics versus Countermeasures of Age Synthesis and Estimation

Tasks	Facts and Characteristics of Face Aging						
	Two-stage Growth	Uncontrollable	Personalized	Attractiveness	Missing Data	Gender	Ethnicity
Age Synthesis	Different growth, development, and aging models: geometry-based, image-based, appearance-based.	Generic models with statistical learning: ASM [76], AAM [123], MM [99], M-face [30], muscle-wrinkle [126], dynamic model [42].	Statistical learning: implicit statistical synthesis [42], [13].	Averageness hypothesis: average face as the origin in the aging space [59]. M-face [30], MM [99]. babyfaceness and average face [60].	Explicit synthesis: data driven synthesis, mechanical synthesis.	Implicit statistical synthesis: MM [99], dynamic model [42].	N/A
Age Estimation	Age group classi-fication and aging pattern or manifold learning, [36], [150] [38], [158], [155].	Online training, universal age estimator [41].	Regression, manifold learning, [36], [16], [150].	N/A	Aging pattern and regression, AGES [37], LARR [16], web data[41].	Gender recognition, [44], [45], [43], [46] [155].	N/A

The age estimation method can be either classification based or regression-based, according to different image representations and databases. For large databases with sequential age labels, both can be applied, while for databases with only age group labels, classification-based methods might be more appropriate. It is interesting to see that some computer-based algorithms can potentially exceed human ability in age estimation. This result may motivate more dedicated studies in this field. In addition to the suggestions of Table 1, there is a couple of promising future directions as follows for age synthesis and estimation via face images:

1) Facial attributes decomposition. When face images show multiple facial attributes, such as identity, expression, gender, age, ethnicity, and pose, the tensor representation (multi-linear analysis) can be adopted to handle uncontrollable and personalized characteristics. Then, the attributes decomposition can be handled via higher order
2) Singular value decomposition. This multi-linear model has more flexibility for age synthesis and estimation. It also might be interesting to investigate the characteristics of aging process in different ethnicity, gender, or both.
3) Generalized aging model. Both age synthesis and estimation share some similar ideas and can help each other. Merging the two modules for generalized aging modeling is beneficial for each one, e.g., two-stage growth and attractiveness. The AAM and “revised” cardioidal strain transformation model are possible examples of such kind of models.

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