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COMPARISON OF SYNTHETIC FACE AGING TO AGE PROGRESSION BY FORENSIC SKETCH ARTIST

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ABSTRACT
Aging affects facial appearance increasingly so through the progression of years of an individual's life. Because of this, there are several human-driven and automated applications that would greatly benefit from the ability to automatically generated accurate images of the appearance of an individual after some time period of aging, particularly when current photographs of the individual are not available. Thus far, however, little progress has been achieved in generating such images beyond those created by traditional artistic methods.

There are a few methods currently used to generate age-progressed facial appearances, mostly for law-enforcement applications such as missing-persons and fugitive apprehension. These methods are artistically driven by individuals trained in art, anatomy, aging, and forensic science. One of the most promising of the few recent computer-based methods for generating images of age-progression uses active-appearance models of the face trained on images of many individuals. This paper presents an initial comparison of synthetic face aging using this method with age progression drawn by a forensic artist.

KEY WORDS
Face, aging, image synthesis, and forensic art.

1. Introduction

Unfortunately, the face cannot escape the effects incurred upon it by the progression of time. There are a variety of changes in appearance that typically occur, and there are also a variety of changes that are individually specific. Lifestyle, race, sun-exposure, weight-gain, expression, and other factors have the potential to affect the facial appearance throughout the aging of an individual. Any such changes in appearance, though, can make it difficult to recognize a person either by human or computer means. Some method of accurately modeling these general and idiosyncratic effects to produce images of age-progression for an individual would serve a variety of applications.

Traditional methods have been successful in a variety of missing-persons cases and in aiding apprehension of fugitives. These methods are typically termed *adult age progression* or *fugitive update* depending on the case. These methods, however, are still driven by input from a forensic artist. Artists are typically trained in a variety of knowledge areas, including drawing, sculpture, human anatomy, effects of aging, and forensic science [1]. Currently such images are produced for forensic and other applications as well as for study of history and anthropology but are not produced through automated means nor with particular scientific rigor. The primary technique used to date is creation of a drawing by a trained forensic sketch artist, incorporating some scientific training in a largely artistic approach to generating facial images. Automated computer methods for generating face images are becoming more popular, and commercial software packages have recently become available, but these are still primarily driven by artist input [2, 1, 3]. Creating methods that automate the generation of more accurate and quantitative age-progressed images could help in law enforcement applications and also improve facial recognition technologies that need to be invariant to or aware of changes in the face due to aging. The capability to model accurate face changes due to age could be used to update a face-recognition training gallery or even be incorporated directly into the face recognition algorithm. Knowledge of facial changes could also be used to focus on recognition techniques that produce age-invariant results.

Several different methods have been considered for computer-based face modeling but little progress has been made in achieving quantitatively accurate models of aging. Some of the methods attempted thus far include image compositing and geometric transformations [6, 7, 8, 9, 10]. One of the most promising methods that has been devised thus far uses active-appearance models (AAM) [11, 12, 13] to generate a face space in which the parameters of individual images may be shifted to generate images that represent the individual at an older or even younger age [14, 17]. Much of this work, though, used a progression of images of individuals that represent *growth and development* not *adult aging*. These are separate processes, though [4]. The first involves large-scale changes in the craniofacial skeletal features toward the formation of the adult skull and face. The second involves minor skeletal changes and larger soft-tissue, muscle, and skin degenerative conditions. This approach has been applied with some initial success to adult aging, though, too [17].

This paper discusses an initial comparison of AAM-based generation of age-progressed images to those created by the most predominant traditional method, age-progression by a forensic sketch artist.

2. Aspects of the Aging Face

Much of the research on how aging affects the appearance of the human face has been concentrated on growth and development from infancy through early adulthood. Changes that take place over the remaining course of lifespan, however, have been more difficult to quantify and understand specifically. The study of changes in the face in general is documented through a variety of anthropological literature that has yet to be used significantly in computer approaches to age progression of the face [1, 3, 4, 5].

Some of the studies undertaken have revealed general trends in timing and patterns of change in the face [2, 5]. Work has been conducted that indicates when and what types of lines and wrinkles form and how skin elasticity and muscle tone diminish over time. Appearance is affected by decreasing muscle tone, diminishing collagen and elastin, and skin wrinkling and sagging. Soft tissue changes are obviously noticeable in the human face throughout the progression of aging, but skeletal changes or remodeling have also been documented [4]. Research has produced evidence for bone-shape changes in the craniofacial region including slight growth in head circumference, head length, width between cheekbones, and face height. Certain changes in the dentoalveolar area and increases in anterior facial height have been found to lead to visual changes in the appearance of the lower portions of the face [1, 5].

The rate of these morphological changes varies. Soft-tissue changes may not be readily apparent in the twenties and thirties but changes escalate during the fifties and sixties [1]. Early changes, though, can include some drooping of the eyelids, horizontal creases in the forehead, nasiolabial lines, lateral orbital lines, circumoral striae, hollowing of the cheek at the inferior border of the zygomatic arch, decrease in upper-lip size, and retrusion of the upper lip [1, 2, 5]. As aging continues, these changes become more noticeable, and by about fifty years, other other changes have begun such as the appearance of numerous fine lines. Skin is also thinner, rougher, drier, and shows loss of elasticity. More wrinkles appear on the face and neck, and discoloration in skin may appear [4, 5].

Normal human variation occurs, of course, and factors such as gender, population of origin, body size, weight, and idiosyncratic behavior all may have an effect on facial appearance. Along with craniofacial remodeling and soft-tissue degeneration, other major factors affecting appearance over age include weight changes, sun-exposure, ancestry, sex, health, disease, drug use, diet, sleep deprivation, biomechanical factors, gravity, and hyper-dynamic facial expressions [3, 4]. Consideration of all of these age-related changes and their influences may be used to inform computer-based models of aging. In the case of this work, the noted soft-tissue and skeletal changes were used to choose a new, larger set of landmarks than used in previous work [14, 17].

3. Age Progression Techniques

3.1. Current Artistic-Driven Methods

The concept of the image update through age progression has been used increasingly more in the last few decades, and there are a variety of current methods for generating age progression of facial appearance. Usually these methods are performed to aid the search for missing persons or to aid apprehension of fugitives. Forensic artists are enlisted to perform these methods. Such artists use a variety of methods of facial update to produce sketches, computer-drawn images, or sculptures. Composite images are also used by forensic artists but are used more often for renderings of individuals by description of witnesses. There are a variety of kits for generating renderings of individuals as well, some performing better than others. Computer-enhanced techniques in current use still require guidance by forensic artist with knowledge of anatomy and aging, and these tend to perform general changes in the face, such as shifting of features and hairline as well as addition of graphic lines and wrinkles. They are not currently based on large, quantitative models of face aging. The most predominant technique for age-progression is still hand-drawn rendering completed by a forensic artist [1].

Forensic artists are usually trained in traditional art, facial anatomy, aging, and forensic science and may be certified by the Forensic Art Certification Board of the International Association for Identification. In order to obtain the second of two levels of certification, a forensic artist needs eighty hours of composite art training, forty hours of related training, five-years experience with a law enforcement agency, five successful drawings, three letters of recommendation, and a sufficient score on a written, practical, and verbal exam [18].

Frank Bender, employed to complete the sketches considered in this work, is a notable forensic sketch artist having contributed both sculptures and age-progression sketches that have helped provide solutions and apprehend fugitives in a variety of high-profile cases. Work in one of his most famous cases led to the arrest of John List, who had been wanted for eighteen years, within two weeks of the national airing of a photo of one of his busts [19]. Another famous case was that of Edmund Solly, apprehended after nearly three decades, when police began to use an age-progressed image drawn by Bender using very old photo references [20].

Forensic artists such as Bender use available photographs of the target individual and family and also ask a variety of questions concerning family background, individual habits, lifestyle, genetic traits, etc. All of the same images used to train the AAM and genetic algorithm for age estimation in the synthesized method were provided to the forensic artist for input to the traditional age-progression process. Given the individual information and images, the sketches at ages 40, 50, 60, and 70 were produced as shown in Figure 1.

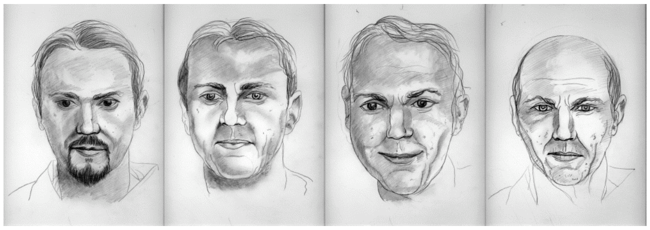

Figure 1: Age-progression by notable forensic artist of the primary author (currently age 34) at ages 40, 50, 60, and 70.

3.2. Synthetic Technique

Family images were compiled for the primary author of this work in a similar manner as would be conducted to provide a forensic sketch artist. These images were used to build a "family face space" using AAM techniques. Images were included from the author in his twenties and early thirties as well as images throughout all available ages for his parents and both sets of grandparents. A sample of family images is shown in Figure 2.

Figure 2: Sample of family images used.

Ninety-nine images were used. Since there were fewer images at older ages, however, several of the images of family members at older ages were repeated in building the AAM to prevent skewing toward younger images. In total, one-hundred and sixty-one landmarks on the face as shown in Figure 3 were used to create the active shape models and have texture samples warped to create the active texture models. The landmarks used in this work are a superset of common anthropometric points and were expanded from a smaller, earlier set in an attempt to better model regions that were likely to change during age progression [17]. Together these models were reduced to fifty-five AAM parameters using the typical PCA method of combining shape and texture coordinates.

3.2.1 Aging Using Active-Appearance Models

The method used to create the synthesized images progressed to different ages uses AAMs and is similar to that in earlier work in growth and development [14] and also in automatic adult age progression [17]. An AAM is generated based on performing principal components analysis (PCA) on parameters of a shape model and a texture model that were each created using PCA on individual shape (landmark location) and texture coordinates from the image set [13]. AAM parameters represent faces using the distance from the average shaped and textured face and may be used to classify faces or synthesize new faces within face space [11, 12].

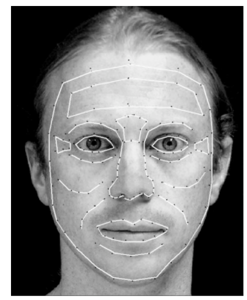

Figure 3: Facial landmarks used for AAM.

3.2.2 Simulation of Aging in Images

Simulating aging of the faces in images was performed using two steps. The first is to estimate the age of a face. The second involves shifting the AAM parameters in the direction of a theoretical "aging" axis.

Estimating the age requires a solution to the equation

$$age_{\mathrm{est}} = \mathbf{W}_1\mathbf{b} + \mathbf{W}_2\mathbf{b}^2 + offset, \qquad (1)$$

where $\mathbf{b}$ and $\mathbf{b}^2$ are the fifty-five AAM parameters and the parameters squared for the given image, $\mathbf{W}_1$ and $\mathbf{W}_2$ are a set of weights to be found to shift the model parameters, and *offset* is a constant to place values in an appropriate range. Representing this equation as an optimization problem, a genetic algorithm (GA) was used to find an appropriate solution [16, 17]. The determined aging function could estimate ages very well in the younger and middle ages where there were more images used for training. After increasing the influence of the older images used for training, though, by adding them to the AAM building multiple times, improvements were made to where the GA was quite accurate on all the images. Table 1 shows results for one of the images of the author at age thirty-four.

The second step of simulating aging may be represented by the equation

$$\mathbf{b}_2 = \mathbf{f}(age_{\mathrm{new}}, \mathbf{b}_1), \qquad (2)$$

where $\mathbf{b}_1$ is the vector of parameters for a given facial image, age_{new} is the desired age to which to transform the

Figure 4: Average family face age-progression sequence.

face image, and $\mathbf{b}_2$ is the vector of parameters generated for the new age. The approach taken in this work is the creation of a lookup table for a "generalized" aging model, in this case based solely on the aging of family members. One hundred thousand random but plausible images were generated using AAM parameters. These images were averaged for each given age and used to populate the table with the average face parameters for a given age. This table represents the generalized aging model and helps illustrate some of the trends that the GA learned in training on the range of ages of faces. Sample images from this are shown in Figure 4. Although images tend to be smoothed somewhat by the AAM technique, there is noticeable texture darkening in the areas of the face discussed earlier concerning aspects of the aging face. Shape also changes slightly, but this is better seen in a succession of images or animation based on these.

To synthesize the image of an individual at a specified age, the original image AAM parameters are transformed. The age of the individual in the image is estimated using the method described above, and the difference of age parameters at the desired age and estimated age is taken from the lookup table. This difference vector is added to the original parameters to generate parameters for an image of that individual at the target age. The resulting face image is synthesized using those parameters.

4. Results and Discussion

4.1. Synthesized Age Progression

A variety of images were age-progressed. Images of the author were "aged" and images of his father and grandfathers were "de-aged." Images were used to make qualitative comparisons and also used in a survey of thirty-seven individuals. This survey was used to make some informal, quantitative judgments of perception of the ages of individuals generated by the AAM method and by the sketch artist.

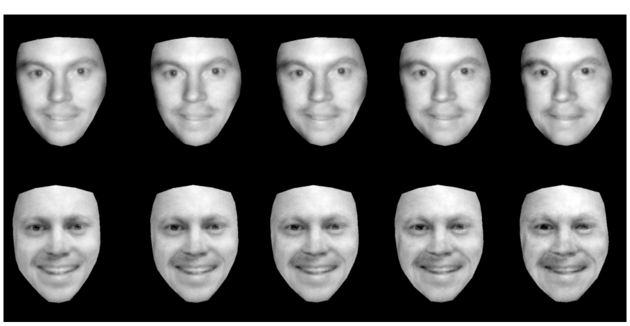

Figure 5: Author age-progressed from ages 23 and 34 respectively to ages 40, 50, 60, and 70 from left to right.

The "aged" images produced a definite appearance of older faces. Changes in the areas noted in the anthropological literature, such as increased nasiolabial and lateral orbital lines as well as small shifts in face shape are present. Slight shifts in the location of particular features are more easily noted when images are viewed in succession, and texture changes are noted as well, although fifty-five AAM parameters still may not represent sufficient texture information for areas such as the forehead to render creases properly. Overall, the AAM model technique does have a smoothing effect on images.

Actual Age	GA Age Estimate
original 34	33.2
progressed 40	39.7
progressed 50	48.9
progressed 60	57.9
progressed 70	65.4

Table 1: Sample genetic algorithm estimates of original and age-progressed image.

Figure 6: Author's grandfather age-progressed in reverse from age 55 to age 25.

De-aged images demonstrate slight changes in location of features as expected and some reduction of texture darkness for lines and wrinkles. Further resolution in both aging and de-aging constructions, however, would likely improve visually age-progressed images produced with this technique.

The synthesized images were compared with those generated by the sketch artist. Most informal responses indicated that the synthesized images looked more like the author, but that the sketched images demonstrated more aging effects. Figure 7 shows a variety of similar images for direct comparison at ages 40, 50, 60, and 70 from left to right.

Figure 7: Comparing various age-progressed images to sketches at ages 40, 50, 60, and 70.

Figure 8 includes a variety of synthetic images of the author at age seventy. Informally, when viewing these images next to images of the same face at younger ages, changes were difficult to perceive and a younger age tended to be estimated, but when viewed separately or in animated succession, changes were noticed and ages were usually perceived to be older.

Figure 8: Various synthetic renderings at age 70.

Table 2 includes results from the survey conducted using thirty-seven individuals. Previous work has shown accurate results in age perception by individuals, but it is affected greatly by texture and other features [10]. The group was shown forty images for approximately ten seconds each and asked to intuitively estimate age without analysis. The images included a variety of real, synthesized, and sketched images. The group average of age estimation was shown to be quite accurate, with an average age estimate error of only 2.6 years on original, unaltered face images. The group had a larger error on the sketches, however, with a group average error of 10.2 years. Several images were simply reconstructed using un-shifted AAM parameters. The group was successful with these as well, with a slightly larger error than that of original images. The synthetic age-progressed images had the worst group average error of 19.5 years, tending to estimate the images much younger than the intended age progression, although "aged" images were typically perceived as older individuals. This is likely due to two reasons: the first is the reduced texture detail due to the model smoothing using only fifty-five parameters to represent a face, the second is that the author was present at the beginning of the study which may have unconsciously affected the estimation of ages of "aged" images of the author. The de-aged image average error was better, closer to that of the forensic sketches. This possibly supports the previous theory. Also, previous work has shown that texture information for distinct wrinkles tends to produce a perception of older age by individuals [10].

Original Image	Forensic Sketches	Reconstructed Images	Aged Images	De-aged Images
2.6 years	10.2 years	3.3 years	19.5 years	11.8 years

Table 2: Average error of age estimate by sample group.

The GA performed better on age estimation on both original images and aged and de-aged images than the group average. These average error estimates are shown in Table 3. It has likely learned a different set of indicators or weighting than those used by human perception.

Original Image	Reconstructed Images	Aged Images	De-aged Images
1.9 years	2.5 years	2.2 years	2.4 years

Table 3: Average error of age by genetic algorithm.

Finally, composite images were made where synthesized faces were placed back into an image with ear and hair. Hair was receded similarly to family members. These images are included for comparison in Figure 9.

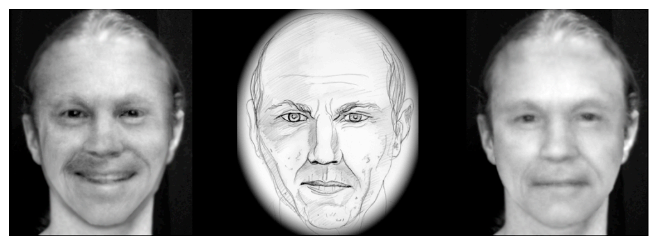

Figure 9: Composite using image age-progressed to 70, sketch at 70, and composite using average family face at 70.

4.2. Discussion of Images and Survey

The increase in the number of landmarks used and the change of location of landmarks to better model face aging, as well as an increase in the number of AAM parameters, did notably improve the visual quality of the images versus earlier work [14]. Initial work with the family images favored younger looking images due to fewer older images used in building the AAM. The repetition of older images to increase their weighting in the model building resulted in more visually apparent age progression.

The images generated do qualitatively demonstrate an increase in age, although it is difficult to quantitatively express this. Texture information does still seem to be overly smooth, as is evidenced by the error in age estimation by the group.

The group survey does seem to indicate that people are good at estimating ages as previous work has suggested [10]. Mild shape change, though, does seem to have less influence on human perception than texture. Improved texture representation will likely improve individuals' perceptions of synthetically aged images as the intended target age. The GA constructed for the aging technique also seems to perform well. It is more accurate on the aged images, perhaps reflecting that it is picking up more on changes of shape and requires less texture information.

5. Conclusion

This method generates images that seem comparable to that of a forensic sketch artist in some qualitative measures, although improvements in texture representation should yield better results. Future work will seek to increase texture resolution and also better quantify the comparison of methods. Other possibilities include incorporating nonlinear shifts of parameters and the use of individualized aging functions and aging functions and methods that include statistically significant guidance of idiosyncratic behavior and other complicating factors such as weight gain or loss that may improve the accuracy of synthetically age progressed images.

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