Analysis of Craniofacial Morphology Changes during Aging and their Connection with Facial Age Estimation

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Abstract. *The aging process affects the structure and appearance of people in different ways. One of such is the change in craniofacial morphology (CM) of individuals. The subject of a person's CM and age estimation is by itself insufficiently researched. Especially on the analysis of children's CM at different ages, because it hasn't been considered thoroughly. This paper will analyze certain characteristics of the CM and their changes during aging from a biometrics perspective, and will also give an overview of previous work on this subject.*

Keywords. Craniofacial morphology, age estimation, anthropometric model, active appearance model, biometrics

1. Introduction

One of the changes during a persons aging process is the change in CM. Different craniofacial characteristics appear at different age and change during the aging process. Analysis of CM can be widely used and has great potential: determining the age of imigrants in situations in which there are no documents that can proove their actual age, for web pages that allow access only for persons above a certain age, for historical photography analysis etc. It can improve face recognition systems (most of face recognition systems are sensitive to changes caused by aging), and can also be used for finding missing people during several years (especially children). Analysis of CM can also improve the human-machine interaction based on age of a person, predict the way a person ages, and facilitate the fight against pedofilia by removing photos of underaged children from the Internet and personal computers.

2. Related work

Many studies related to CM of individuals from different aspects have been conducted. One of these studies was one conducted by Coleman and Grover [1] which refers to changes in the three-dimensional human face geometry during the aging process. Coleman and Grover conducted this research in terms of plastic surgery, in order to cancel the results of aging. They have focused on adults and unwanted changes on the face during the aging process. Some of the changes they stated, and according to which it is possible to discern the age of people are: (1) reduction in the height of the face, (2) increase in the width and depth of the face, and (3) facial features (nose, chin) become more distinct. They also divide the face into thirds and claim that human beauty is contained in the central part of the face.

Ricanek et al. [9] researched the craniofacial characteristics of aging in terms of building more robust systems for face recognition in biometrics. They provide an overview of changes in facial structure and soft tissues over the years.

A study conducted by Gao and Ai [3] refers to the use of Gabor filters and fuzzy LDA method to classify individuals into groups: baby, child, adult and elderly persons. The paper presents a mathematical background for defining individual's affiliation to a certain group.

There have been many other studies related to the analysis of CM: Lanitis [5] studied CM in terms of face recognition or authentication of individuals based on facial images. Ramesh et al. [8] proposed a new algorithm for face recognition and classification of people according to sex and age, which gives very good results with a relatively small set of images for learning. Patterson et al. [6] suggest the use of an ageing function based on an Active appearance model that uses the principal component analysis (PCA) method. Olle Pettersson uses the learning vector quantization (LVQ) method for classification of faces regarding age in his Master of Science Thesis [7].

Kwon and Lobo [11] proposed a theory and practical calculations for age classification of facial images in 1994. Their calculations are based on CM of individuals and wrinkle analysis. They divide facial characteristics into primary and secondary, and, during the implementation of the theory, firstly seek primary face characteristics (eyes, nose, mouth, chin, top of the head and left and right side of the head), and secondary characteristics afterwards. From the primary characteristics they calculate ratios based on which a person is classified into three classes (children, young adults and older adults). During analysis of secondary characteristics they use a wrinkle map for detection and measurement of wrinkles on the face. Combining the analysis of ratios of the primary characteristics and wrinkle analysis, faces are classified into three classes mentioned earlier.

3. Changes in craniofacial morphology of individuals

Geng et al. in their work on automatic facial age estimation recognize two facial aging stages. First stage is early age, defined as age from birth to adulthood. In this stage, most changes are changes caused by craniofacial growth [4], as shown on Fig.1:

- Forehead slopes back, shrinks and releases spaces on the surface of the cranium,
- Facial features expand their areas and cover the interstitial spaces,
- Cheeks extend to larger areas,
- Chin becomes more protrusive.

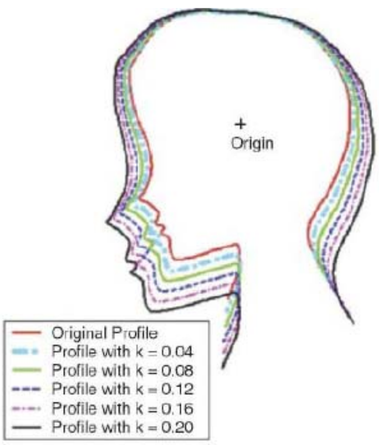

Figure 1. Shape changes caused by craniofacial growth – Todd et al. [10]

Besides shape changes caused by craniofacial growth there are also minor skin changes [4]:

- Facial hairs become dense and change color and
- Skin color slightly changes

The second stage of facial aging recognized by Geng et al. [4] is during the adulthood. Adulthood is defined as the time from the start of adulthood to old age. Main changes in this stage are skin changes. Skin becomes thinner, darker, less elastic and more leathery. Also, wrinkles, blemishes, double chin, dropping cheek and eyelid bags appear. But there is also some minor craniofacial growth in this stage, mostly changes in face shape, but most of the craniofacial growth happens in early age of an individual, as it can be seen on Fig. 2.

Figure 2. Craniofacial changes during aging from FG-NET database

4. Age estimation

Age estimation could be defined as determination of an individual's age or his/her age group. A person's age can be determined in many ways, but this paper focuses on age determination based on facial images.

According to Geng et al. [4], there are several types of ages:

- Actual or chronological age is defined as the number of years a person has lived.
- Appearance age is age information defined by person’s visual appearance
- Perceived age is defined by human subjects based on visual appearance of a person
- Estimated age is age defined by machine from visual appearance

Appearance age is usually very close to actual or chronological age of a person. The objective of age estimation is that the estimated age is as close to appearance age as possible.

5. Models of the aging face

There are many different models of the aging face. Some of them have been recognized in Geng et al. [4]:

- Anthropometric models - based on the measurements and proportions of the human faces
- Active appearance models - based on the statistical face model AAM
- Aging pattern subspace - based on the AGES method proposed by Geng et al.
- Age manifold - based on the manifold embedding techniques to learn the low-dimensional aging trend
- Appearance feature models - based on aging-related features extracted from face images

5.1. Anthropometric model

The anthropometric model is based on human face ratio, as shown on figures 3-9.

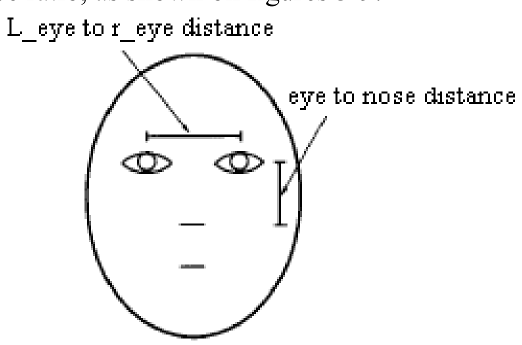

Figure 3. Ratio 1 on human face [6]

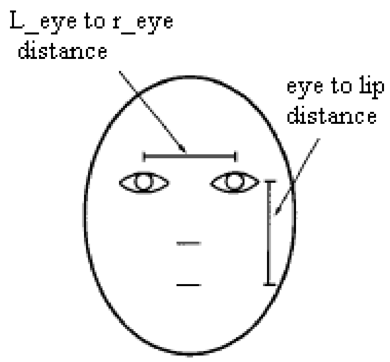

Figure 4. Ratio 2 on human face [6]

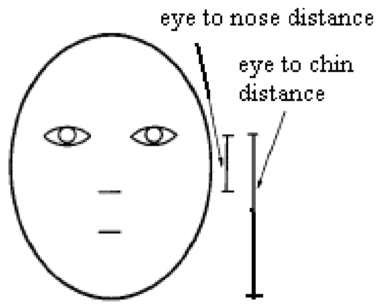

Figure 5. Ratio 3 on human face [6]

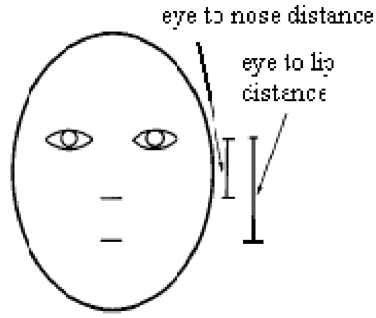

Figure 6. Ratio 4 on human face [6]

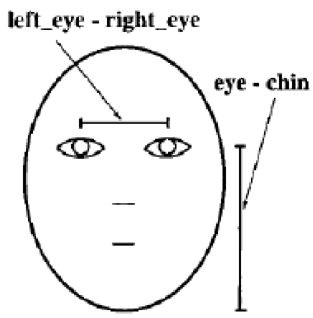

Figure 7. Ratio 5 on human face [6]

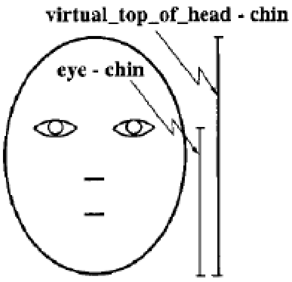

Figure 8. Ratio 6 on human face [6]

This model is useful for classification of humans into minors and adults, but it can’t distinguish between different ages of adults [4], for example, young adults and seniors. This is the main reason why Kwon and Lobo [11] used wrinkle analysis to do the separation between young adults and seniors.

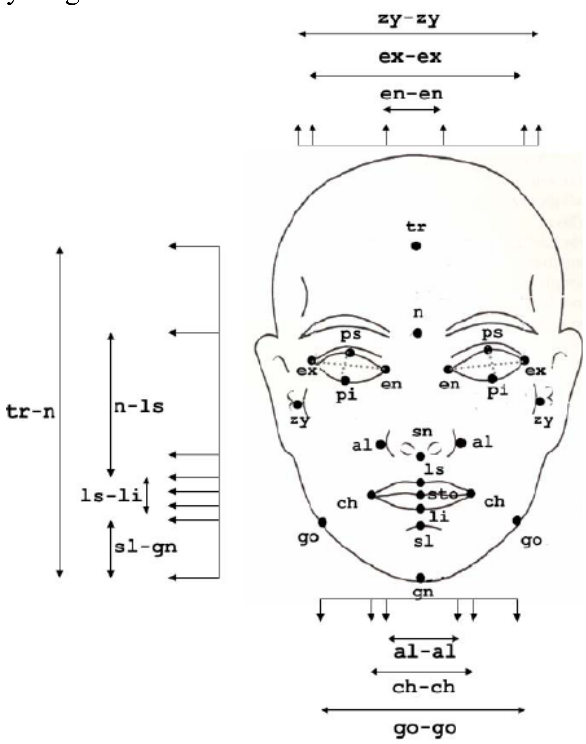

Figure 9. Facial characteristics ratios – Geng et al. [4]

5.2. Active Appearance Model

The active appearance model was developed by Cootes, Edwards and Taylor [2]. It is an algorithm for matching a statistical model of object shape and appearance to a new image. They are built during a training phase and by taking advantage of the least squares techniques, it can match to new images easily. The active appearance model is related to the active shape model. One disadvantage of active shape model is that it only uses shape constraints and does not take advantage of all the available information, especially the texture across the target object. This can be modeled using an active appearance model [2].

This model requires a training set of annotated images where the landmark points have been marked on each example (Fig. 10).

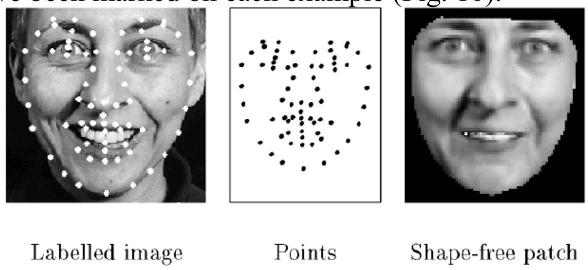

Figure 10. Marked landmark points – Geng et al.[4]

AGES algorithm developed by Geng et al., among others, also uses this active appearance model.

6. Discussion

Main objection to Geng et al.[4] paper is the number of facial aging stages. Human facial aging is a delicate process, with many changes especially during growth from a baby to young adult. Because of that, the first stage could be divided in to several stages, for example baby, child, teenager and young adult.

It must be stated that the active appearance model [4] has its advantages over anthropometric model, as shown in Table 1.:

- it considers both the shape and texture, while the anthropometric model only involve facial geometry
- it can deal with any age, while the anthropometric model can be only used to distinguish minors from adults
- it is robust against head poses, while the anthropometric model is quite sensitive to poses

Table 1. Differences between Anthropometric model and active appearance model

	Shape	Texture	Any age	Head poses
Anthropometric model	√	x	x	x
Active appearance model	√	√	√	√

7. Conclusion

Subject of CM of individuals regarding age is by itself insufficiently researched. Earlier research defines face characteristics important for defining an age group of a person. Future work will show the possibility of defining an age group a person belongs to based on the middle part of an individual's face (from upper point of eyebrows to lower point of lips) and will concentrate on facial age estimation based on images of children and young adults to better distinguish the difference between babies, toddlers, children, teenagers and young adults.

8. References

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