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Technical Section

Realistic wrinkle generation for 3D face modeling based on automatically extracted curves and improved shape control functions ☆

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ABSTRACT

Realistic wrinkles are extremely important for enhancing the realism of three-dimensional (3D) virtual face models. This paper proposes an approach for generating realistic wrinkle on a 3D face model based on a face image. It includes image preprocessing, automatically extracting wrinkle curves and generating wrinkles on a 3D surface. For image preprocessing, we use a linear transform method to conduct a grayscale conversion. We then use a transfinite-pixel neighborhood averaging method to reduce the noise, and a high pass filter to sharpen the image. For the automatic extraction of wrinkle curves, an improved Canny edge detector is employed. For wrinkle generation on a 3D surface, a number of novel techniques are employed. Some feature points are firstly defined both on the face image and on the 3D face model. By aligning these feature points, the extracted wrinkle curves are then projected onto the 3D face model. Finally, three shape control functions are used to produce more realistic properties of the 3D wrinkles. They are the proposed cross-section shape control function (CSCF) to determine the cross-section shape and size, the depth attenuation function (DAF) and the width attenuation function (WAF) to control the depth and width amplitude variations of the wrinkles, respectively. For better results, an adaptive subdivision is applied to the predefined influence region to adjust the resolution around the wrinkle mesh. The experiment results of applying this method to individualized 3D human models demonstrate the ability of our method to generate more natural wrinkles.

1. Introduction

Individualized three-dimensional (3D) face modeling has been an active area in computer graphics, virtual reality and artificial intelligence, because of the emergence of versatile applications in character animation for films and advertising, character craftwork manufacturing, computer games, and so on [1]. However, creating individualized 3D face models requires not only the verisimilitude of the main facial features, but also subtle facial features like wrinkles. These details constitute the major factors affecting the visual appearance of the face because they not only show a person's age, they are also important to convey a person's inner world. Therefore, modeling realistic wrinkles contributes significantly to the realism of 3D face modeling.

Modeling realistic and natural wrinkles, however, is a complex, time-consuming, and tedious job. In all methods of wrinkle modeling, we encounter three major problems: (1) accurate location of the wrinkle; (2) realistic shape representation for various wrinkles; and (3) the speed of wrinkle modeling. Many researchers [2–4] have drawn the wrinkle curves by hand, but it is difficult to ensure the accurate locations and shapes of the wrinkle curves using this technique, and it is time-consuming. By studying the current work on wrinkle modeling and understanding the properties of real wrinkles, we present an approach for efficiently creating realistic wrinkles on a 3D face model based on a given image. Our approach applies a series of techniques through each stage of wrinkle modeling. This process allows us to automatically extract the wrinkle curves from the image, obtain their accurate locations, naturally shape them, and effectively generate them on a 3D face model.

In our approach, a series of preprocessing measures are first applied to the image for automatic wrinkle curve extraction. These measures include a linear transform method to conduct grayscale conversion, a transfinite-pixel neighborhood averaging method to reduce the noise, and a high pass filter to sharpen the image. After the image is processed, an improved Canny edge detector is employed to automatically extract wrinkle curves from the image to obtain their precise locations. Then, a set of improved shape control functions is applied to the extracted wrinkle curves. The cross-section shape control function (CSCF) easily expresses the shapes of the inward furrow and the outward bulge. The depth attenuation function (DAF) and width attenuation function (WAF) can describe the variations of depth and

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width, respectively. These functions allow users to easily model various wrinkles as they desire by setting different parameter values. Meanwhile, the adaptive subdivision technique is employed to refine the created wrinkle curves. This step can further enhance the results of wrinkle generation and save computing time. Finally, our experimental results show that our approach provides solutions to the aforementioned three problems—accurate location, realistic shape modeling, and speed—which are the major contributions of our work.

The remainder of the paper is organized as follows: We first discuss previous related works in Section 2. Section 3 introduces the properties of wrinkles. Section 4 describes the overall algorithm of our wrinkle modeling approach, which is followed by detailed descriptions of the image preprocessing, automatic extracting of wrinkle curves, shape control functions, and generating wrinkles on a 3D surface. Section 5 presents the experimental results and the discussion. The conclusions and suggestions for future work are given in Section 6.

2. Related work

There are currently three mainstream methods of creating wrinkles, namely, texture techniques, physically based methods, and geometric methods.

Texture techniques use color texture mapping for wrinkle modeling [5–7]. Color mapping alters the shading of a surface to give the visual impression of wrinkles without deforming the geometry. This method is efficient and can give acceptable visual results in simulating or animating facial wrinkles. However, this method has some inherent limitations. The skin geometry remains undeformed, and the perceptible geometrical and structural changes cannot be modeled. Thus, the skin model with wrinkles can meet the visual effects to some degree, but it cannot be used, for example, for individualized character craftwork manufacturing.

Physically based methods intend to model and simulate the true biological forms and functions of human skin and to simulate the dynamics of wrinkles by way of skin deformation. Typical methods are the mass–spring and finite element methods. The mass–spring method can be traced to the pioneering works of Platt and Waters. Platt modeled the skin surface as a mesh of interconnected springs connected to the underlying bone structure through simulated muscles, and the entire system was simulated as a mass–spring complex [8–10]. Waters followed by allowing for the modeling and simulation of more complex muscle–skin systems wherein different types of muscles were modeled [11]. Afterward, Zhang proposed a mass–spring system with nonlinear springs. This system had a biphasic stress–strain relationship to simulate the elastic dynamics of real facially expressive wrinkles [12] and a subsequent multi-layer deformation model [13,14]. However, the mass–spring model is time-consuming and computationally complex. The teams of Wu and Thalmann were also committed to physically based wrinkle modeling for some time [15–18]. They presented a finite element model for creating expressive and aging wrinkles, respectively. Boissieux et al. [17] improved the model presented by Ref. [19], and the wrinkles generated by their amelioration arithmetic technique were more real. Additionally, a three-layered deformable lattice structure [20] for facial tissues was proposed, which produced some of the expressive wrinkles that occur during skin deformation. These physically based modeling methods can provide real and natural wrinkle shapes, but the process requires a greater amount of computation, and it is difficult for users to directly manipulate of wrinkles and employ the wrinkle patterns acquired from actual skin samples or images.

Geometric modeling methods generate wrinkles according to the geometric structure of the skin and wrinkles, and they solve the difficulties associated with the two types of methods mentioned earlier by producing a perceptible geometrical deformation of skin for rendering at a high simulation speed. Some researchers have proposed a curve/curvature-driven model using the particle energies to control various wrinkle shapes. For example,
Venkataraman et al. [21] proposed a curvature-driven kinematics to form wrinkles. The final shape was obtained by minimizing functions that included energies or costs for stretching, bending, and self-intersection. Wang et al. [4] proposed an energy-based, curve-driven technique. In this approach, surface wrinkles were generated by deforming the given mesh surface according to the shape change of a governing curve on the surface, but all of the control curves were drawn by users. Cutler et al. [22] presented an art-directed wrinkle system for CG characters, and they extended their approach to achieve believable age wrinkles for characters' skin. However, the location of the wrinkle patterns was performed by placing a set of shape points by hand. Li et al. [23] presented an approach for modeling dynamic wrinkles of the face through subdividing the facial region and moving the key nodes to deform the facial mesh. Although these geometric methods are efficient and produce convincing results, they present difficulties in intuitive control, such as the location of wrinkles and adjusting the shapes. The curve/curvature-driven method and Li's method involve painstaking tasks, such as manually drawing wrinkle patterns in textures and subdividing the wrinkle regions.

Many researchers [2,3,7,24,25] have presented a shape control function to deform the surface mesh to generate wrinkles. Bando et al. [3] proposed a method for generating fine-scale wrinkles and large-scale wrinkles, respectively. Zhang et al. [24] presented an anatomy-based face model with adaptive refinement for simulating wrinkles in facial expressions. Li et al. [25] improved the method presented by Bando et al. in three aspects: the extraction of partition wrinkle line features, the fractal coarse wrinkle lines replaced the smooth ones, and the wrinkle shapes. Similar to the idea of Bando and Li, our method also uses the shape control function to deform the 3D mesh, but we first take a series of measures to enhance the image for preferably extracting wrinkle curves, and we use the improved edge detection algorithm to automatically extract the wrinkle curves based on the face image. Moreover, we propose an improved cross-section shape function, and we take into account the amplitude variations of a wrinkle in the depth and width directions, which can easily and realistically describe the properties of natural wrinkles. Additionally, we use an adaptive subdivision technique in the predefined influence region to save computing time. Therefore, accurate location, realistic shape modeling, and speed are the major contributions of our work.

3. Properties of the wrinkle

To enhance the verisimilitude of wrinkle modeling, it is necessary to study and analyze the physiology to determine the wrinkle's characteristics and attributes. From the view of medical histology, wrinkles are generated mainly due to the atrophy of the elastic fibers, connective tissue, and skin fibers in the dermal tissue of the skin as well as the reduction of moisture, fat, and subcutaneous fat within the epidermis and dermis [26]. Wrinkles can be classified into three types according to the reasons of their generation: (1) superficial fine wrinkles; (2) aging wrinkles; and (3) expressive wrinkles. Aging wrinkles are perpetual, and once they appear on the face, they become gradually more conspicuous