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基于草图的花开建模与动画*

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Sketch-Based Modeling and Animation of Floral Blossom

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Abstract: Traditionally, synthesizing the animation of floral blossom is accomplished mostly manually and hence a time-consuming and laborious task. This paper proposes an interactive biology-based flower modeling and animating approach. It models the initial shape of the floral components including petal, pistil, stamen and pedicel, and two terminal status of floral blossom with a sketch-based interface. The subtle geometry of the whole flower is created according to the phyllotactic rules. Then, it extracts a set of growth parameters for describing the floral blossom, and builds a dynamic growth model to regulate the continuous morphing of floral components in the process of blossom. Finally, a sequence of naturally deforming flower models is generated with these parameters. The initial experimental results demonstrate that this approach can efficiently generate visually pleasing simulation of floral blossom, which is consistent with biological rules.
Key words: plant; floral blossom; sketch-based modeling; dynamic growth model; computer animation

摘 要: 合成花开动画一般靠手工交互完成,费时又繁琐.提出了一种基于生物学的交互式花朵建模和花开模拟方法.首先采用基于草图的建模方法对花朵的器官,如花瓣、雌蕊、雄蕊和花梗等进行初始形状设定;利用植物学中的叶序规则,构建花苞和成花的完整细节模型.然后,分析比对花朵的主要器官花开前后的姿态和尺寸,提取出一系列描述花朵的生长参数,建立一个动态生长模型,并以之指导花朵器官在花开过程中的连续形变.最后,依据生长模型生成一个逐渐开放的花朵模型序列,依次绘制该序列即可合成逼真的花开动画.实验表明,该方法高效、简洁,能够获得既符合生物学规则又具有视觉美感的花开模拟效果,可广泛应用于生物学仿真、虚拟现实、计算机动画以及视频游戏等领域.
关键词: 植物;花开;基于草图的建模;生长模型;计算机动画

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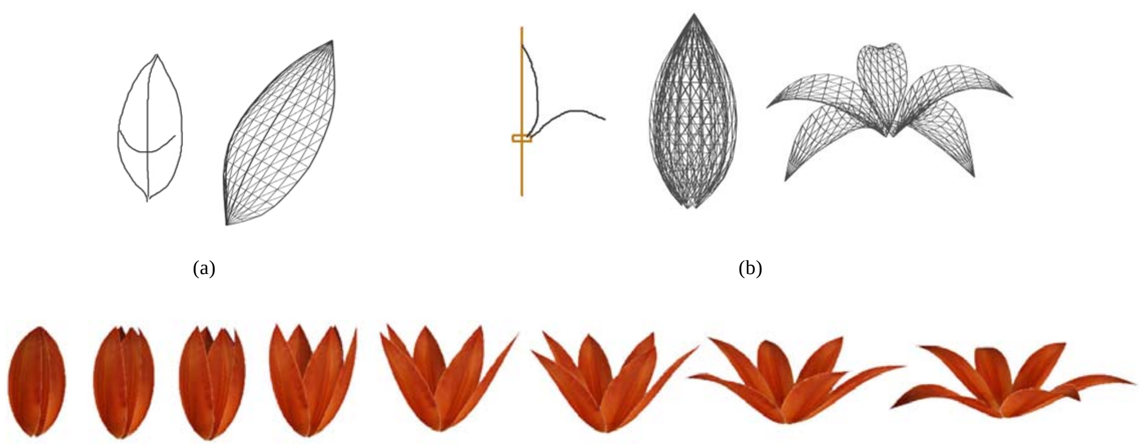
1 Introduction

In the natural world, flowers and floral blossom are highly appreciated for their beauty and vividness. Faithful simulation of floral blossom has been an attractive yet difficult job in many graphics-related applications like video game and virtual reality. Due to the geometrical and biological complexity of the floral structure and floral blossom, there has not been yet an interactive or automatic approach for animating a flower. Although well-established plant modeling techniques such as L-system[1] and Xfrog[2] can fulfill this goal to some extent, they have been proven to be inefficient for designing visually plausible floral blossom. In practice, artists resort to manual modeling and animation softwares, or employ key-frame and shape morphing techniques.

The goal of this paper is to model flowers and animate floral blossom with production-ready visual realism, in an intuitive and interactive fashion. It should be easy-to-use and simple enough for novice users, i.e., it should require as minimal as possible user interaction on manipulating control points and adjusting shape parameters. Our solution is a sketch-based interface for modeling flower geometry and a biology-driven approach for simulating floral blossom. The sketch-based interface allows the user to specify the representative shape of individual floral components (Fig.1(a)) and the overall shape of the starting and ending frames of a flower blossom process (Fig.1(b)). Thereafter, a geometric flower model is quickly constructed based on well-studied phyllotactic rules. We then extract a set of growth parameters from the variations of floral components in the two frames. Based on these parameters and growth functions, our system builds a dynamic growth model which describes the continuous variations of individual elements during floral blossom. Finally, a sequence of models for all animation frames can be conveniently constructed on-the-fly with this growth model, as shown in Fig.1(c).



(a) (b)

(c)

Fig.1 To simulate the floral blossom.

(a) Designing floral components with a sketch-based interface,

(b) Specifying the starting and ending status of a whole flower,

(c) A sequence of gradually deforming flower models during blossom

In summary, this paper presents two main contributions:

- We simplify the procedure of modeling flower and animating floral blossom by employing a sketch-based and biology-driven approach.
- We establish a dynamic growth model under biological principles to simulate the continuous deformation of the floral blossom.

After discussing the related work in Section 2, we describe our sketching approach in Section 3. Section 4 presents how to construct the dynamic growth model. Experimental results are presented in Section 5, followed by the conclusion and future work in Section 6.

2 Related Work

Procedural plant modeling: As a well-known plant modeling approach, L-system[1] encodes the plant structures with a set of string rewriting rules and generates a wide variety of plant models by adjusting parameters. Its extensions, the timed L-system and differential L-system (*d*L-system)[3], exploit both the discrete and continuous aspects of the plant evolution and can be used to simulate the plant growth. Although the L-system scheme can be made more intuitive by using certain position control functions[4], it is still inconvenient to design suitable rules for faithfully simulating complex shape deformation procedure such as floral blossom.

Component-Based plant modeling: The commercial system Xfrog[2] combines the advantages of the rule-based and parameterized-based modeling schemes, yielding highly realistic plant models. It provides an intuitive interface to manipulate the plant components and design key frames of a plant animation process. The main disadvantage of this scheme lies on complicated parameters adjustment, which seems to be difficult for an inexperienced user to quickly achieve desirable effects. Besides, it lacks of a way for effective animation design of plants.

Sketch-Based plant modeling: Sketch-Based modeling techniques allow a user to easily create a rough model from several strokes. Representative systems include SKETCH[5], and Teddy[6]. As the plant modeling is concerned, Okabe, *et al*.[7] introduced a sketch-based tree modeling system that assumes the branches to be separated from each other. Ijiri, *et al*.[8] developed a floral diagram based flower modeling system that uses inflorescence as structural constraints. By integrating the initial sketching and subsequent detail editing in a top-down mode, Ijiri, *et al*.[9] achieves higher modeling efficiency compared to [8]. Later, Anastacio, *et al*.[10] adopted concept sketches to model single-compound plant structures for the purpose of non-photorealistic rendering. To our best knowledge, there has not work that is capable of designing the dynamic plant growth with a sketch-based interface.

Biology-Driven plant modeling: Recently, in the field of plant biology, computational plant models are increasingly employed for comprehending complex relationships between gene function, plant physiology, plant development and plant form. Roughly speaking, the plant modeling targets can be divided into three classes[11], namely, the models for plant architecture, organs and tissues, and the incorporation of genetic regulatory networks. The first class deals with the arrangement of components in a branching structure, which is the focus of this paper. Comparatively, the second class handles the arrangement of components extended from areas or volume. And the third one considers the processes within individual cells.

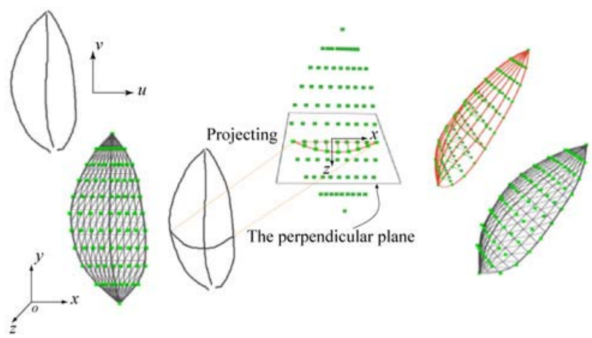
3 Sketch-Based Flower Modeling

Sketch-Based modeling scheme provides a convenient interface for fast prototype construction. We employ this scheme for the generation of flower models at various statuses, which is then used for the construction of the dynamic growth model. The whole geometry of a flower is created adhering to a set of geometric constraints and *phyllotactic rules*.

3.1 Generating flower components

Beginning with the 2D strokes indicating the abstractive shape of floral components, the key issue is how to translate these conceptual designs into a geometric specification. Our solution for petal and sepal is similar to the one presented in [9]. We take the petal as an example to describe our approach.

Specifically, we represent a petal as a B-spline surface. The user needs only to draw three strokes representing the outline and primary vein of the underlying petal respectively. Our system automatically generates the control points of the B-spline surface, which are equally distributed in the horizontal (u) and vertical (v) directions (see Fig.2(a)). To fulfill this, our system first constructs a flat B-spline surface on the base plane, i.e., the o-xy plane. When the user draws a modified stroke in the u direction that indicates the cross-section curve of the petal, our system searches out a row (along the u direction) of control points whose v coordinates are nearest to the starting point of this stroke and marks them as target control points. The modified stroke is then projected into a plane which is perpendicular to the base plane and passes through the control points, called the perpendicular plane, and approximated with a B-spline curve. Our system maps target control points onto the B-spline curve (Fig.2(b)). Thereafter, each column (along the v direction) of control points are translated to new positions by means of cubic B-spline interpolation (with three points and two edge conditions), leading to a vibrated petal shape (Fig.2(c)). The resultant model can be stored as a petal template.



(a) (b) (c)

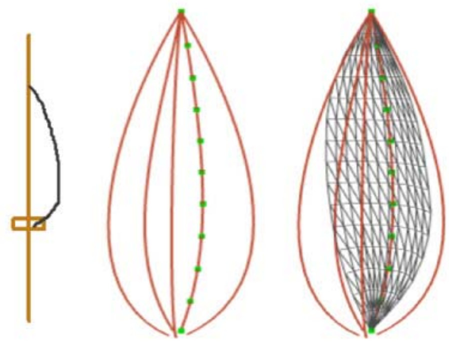
Fig.2 Modeling of the petal. (a) The specification of the petal edges and primary vein on the base plane. (b) Mapping a modified stroke to an arc on the perpendicular plane. (c) The vibrated petal

3.2 Assembling flower models

To determine the growth parameters for the dynamic growth model, the starting and ending statuses of the floral blossom are required. This means, we need to construct at least two geometric flower models to represent the blossom procedure. Similar to the modeling of floral components, we employ a sketch-based approach to construct the flower bud and the opened flower model. After the user draws two strokes to indicate two desired blossom configurations, our system quickly assembles the desired models.

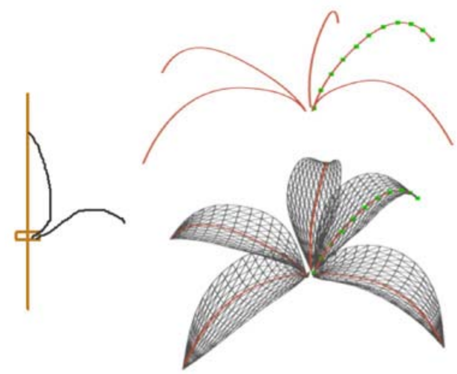
Modeling the flower bud: The user first draws a curved stroke indicating the outline of a flower bud (Fig.3(a)). Our system considers it as the initial form of the primary vein of one petal and reproduces a full flower bud based on the *phyllotactic rules*[12], which state that the divergence angle between consecutive organs is approximately the Fibonacci angle, i.e., $360° \ \tau^{-2} \approx 137.5°$. Along every other 137.5° around the center axis, we generate a B-spline curve to approximate the one drawn by the user and forms the primary vein of a new petal (Fig.3(b)). We call it the initial anchor curve. Subsequently, a group of petal instances are created from the petal templates that are pre-built as described in Section 3.1. Finally, they are transformed to ensure the primary veins of individual petals to be aligned with the petal curves (Fig.3(c)).

Modeling the opened flower: As the user draws a free-form stroke apart from the central axis (Fig.4(a)), our system treats it as the terminal form of the primary vein of a petal. Similarly, a set of curves is generated in the local frames determined by the existing initial anchor curve, which are called the terminal anchor curves. Like the technique for the flower bud, we create the petal instances and assemble them into a whole flower model (Fig.4(b)).



(a) (b) (c)

Fig.3 Assembling of the flower bud



(a) (b)

Fig.4 Assembling of the opened flower

4 Designing Flower Animation

Typically, the regional differentiation of auxin in growth zones is employed to simulate the variation of growing plants[13]. Instead, we adopt a different notion presented by biologists recently to depict the growth of flowers. In this notion, the growth properties of plant components are decomposed into three growth parameters, which are adequately intuitive and amenable in computer graphics. We also adopt an empirical function in biology to regulate the gradual evolution of floral components. We parse and analyze the models of the flower bud and the opened flower, and retrieve these parameters to capture the growth properties. Finally, we extend the growth functions to be more flexible, and combine with the extracted growth parameters to create a dynamic sequence of the flower models from a bud to the final status. Note that, the deformation of petals is the main visual feature of the floral blossom, and thus we focus on the modeling procedure of a petal in the following subsection.

4.1 The growth parameters and functions

The growth parameters: From the viewpoint of Rolland[14], the shape variation of a growing structure depends on the growth properties of its components. For each region at each time point, these properties can be captured by three types of parameters, namely, the increasing rate in size (the growth rate), the growth change along each direction (the anisotropy) and the growth direction relative to a canonical coordinate system (the direction) (Fig.5(a)). These parameters are usually determined with biological experiments.

The growth functions: Biologically, the *growth functions*[2] are used to describe continuous processes such as the expansion of cells, the elongation of internodes and the gradual increase of the branching angles over time. These functions are built by mathematical fitting to statistical data. For instance, the growth functions for high plants are usually in sigmoidal type, because they increase slowly at the beginning, and then accelerate growing gradually. A popular form of the growth function is the logistic function, defined by the following equation:

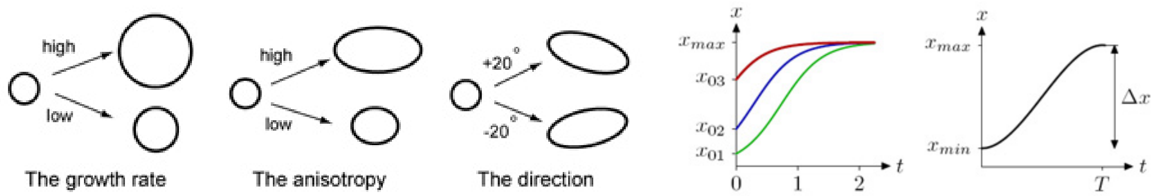
$$\frac{\mathrm{d}x}{\mathrm{d}t} = r\left(1 - \frac{x}{x_{\max}}\right)x \tag{1}$$

where $x_{\max}$ is the maximum value, and r is the growth rate. The initial value x_0 can be chosen properly (Fig.5(b)).

Another explicit and convenient form is represented by a cubic function of time:

$$x(t) = -2\frac{\Delta x}{T^3}t^3 + 3\frac{\Delta x}{T^2}t^2 + x_{\min} \tag{2}$$

where $\Delta x = x_{\max} - x_{\min}$ and $t \in [0, T]$ (Fig.5(c)). It basically increases sigmoidally from $x_{\min}$ to $x_{\max}$.



(a) (b) (c)

Fig.5 Illustrations of the growth parameters and the growth functions.

(a) Three growth parameters.

(b) A family of the logistic functions which have different initial value x_0.

(c) A cubic function

4.2 Specifying the growth variations

Plant biologists use tracking methods or clonal analysis to observe the evolution of the plant components, and estimate the growth parameters by means of measurements and comparisons. Our scheme is different in that we first compare and analyze the geometry of flower models at different stages and extract the growth parameters, and then determine the growth variations for describing the growth parameters of petals during blossom.

The growth parameters are originally used to describe the component properties. For the purpose of simplicity, we translate them into a set of control meshes of the petal objects, which are represented by B-spline surfaces. Consequently, the shape of petals is adjusted in an indirect fashion. Firstly, we parse the control meshes of a petal at the starting and ending status into a temporal sequence of cells and index the cells on each control mesh sequentially in the u and v directions. The two corresponding cells on the starting and ending control meshes are defined as the corresponding cell pair. For each cell, we assign a growth property ellipse that locates at its center. Its minor axis and major axis are parallel to the mean u and mean v direction vectors respectively and its radii along both axe are proportional to the average lengths of the u and v directions (Fig.6).

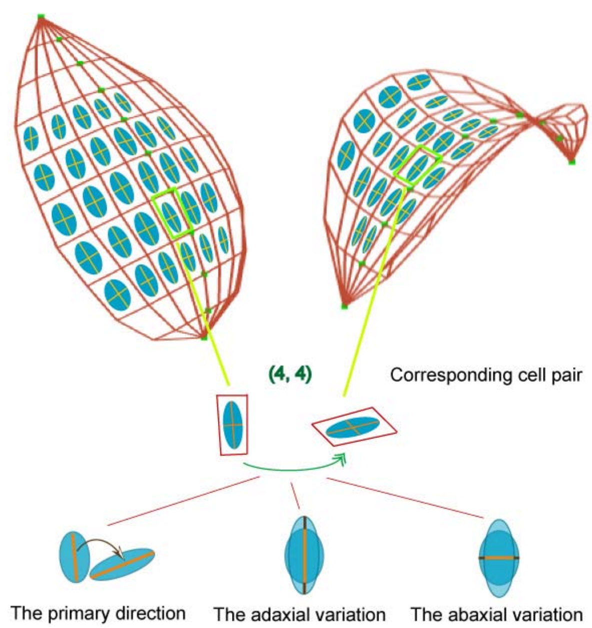


Fig.6 The specification of the growth variation

For each grid pair, we compare their growth property ellipses and extract the growth parameters. The transformation from the major axis of the starting ellipse to that of the ending ellipse is represented by a quaternion. We call it the primary growth direction. In addition, the length ratio of the starting major axis to the ending major axis is called the adaxial growth variation. The length ratio of two minor axe is called the abaxial growth variation (Fig.6). These two parameters take different form from the definition of the growth rate and the anisotropy. They are, however, equivalent to their combination and are more intuitive and effective for control and computation. We evaluate three aforementioned growth parameters and employ them to determine the growth variation of a cell of the control mesh.

4.3 Constructing dynamic growth model

With the computed growth parameters, we need to evaluate a dynamic growth model to regulate its continuous growth. In practice, we regard the growth function as the formulation of the continuous deformation of a petal. By exploiting the flexibility of the time modulation, we derive a mixing growth function to take advantage of both the logistic function and cubic function.

In fact, an equivalent differential equation of Eq.(2) one time t is:

$$\frac{\mathrm{d}x}{\mathrm{d}t} = c\frac{\Delta x}{T}\left(1-\frac{t}{T}\right)\frac{t}{T} \tag{3}$$

Formally, it is analogous to the logistic function. The difference lies in that it takes a constant growth rate with a user-determined constant coefficient once Δx and T are specified, while the logistic function has a variable growth rate r. For simplicity, we denote $c\frac{\Delta x}{T}$ in Eq.(3) with an adjusting variable g. One immediate profit of this function is that, we can still change the time interval T to specify the total growing time, which is not contained in the logistic function. These yield the final growth function:

$$G(t;g,T) = -g\frac{\Delta G}{3T^3}t^3 + g\frac{\Delta G}{2T^2}t^2 + G_{\min} \tag{4}$$

where $\Delta G = G_{\max} - G_{\min}$ and $t \in [0,T]$. By changing the value of parameters of growth rate g and the time interval T, it is quite flexible to modulate the procedure of floral blossom. Finally, the dynamic growth model for petals is expressed as the integration of the grow functions G with the collection of the growth parameters $\boldsymbol{P}$:

$$DGM: \begin{cases} G_{\boldsymbol{P}}(t;g,T) \\ \boldsymbol{P} = (\boldsymbol{pd}, dv, bv) \end{cases} \tag{5}$$

It is convenient to apply the growth functions with the growth parameters, i.e., the adaxial growth variation (dv) and the abaxial growth variation (bv), to interpolate the intermediate values. However, for the primary growth direction, it is much more complex. Because the primary growth direction (***pd***) is denoted as a quaternion, we may not achieve desirable effects by performing direct operations. Fortunately, the spherical linear interpolation of quaternion works well to serve our purpose. In order to adjust the variation timing, we introduce a velocity curve to modulate the input parameters for the spherical linear interpolation function. If the velocity curve is compatible with the defined growth function, a coherent variation can be obtained.

5 Results and Discussion

We have implemented a prototype framework and conducted several experiments. The first example is a golden lily. Without any botanic knowledge, a novice user can draw a set of conceptual strokes to express the intuition on the petal shape and the blossom configuration. Our system automatically generates the desired geometry of them.

The overall user time spent on the sketch-based modeling is less than three minutes. Fig.2~Fig.4 show that the petals generated by the system. It is apparent that these shapes reflect the creation intuition and the two terminal models preserve the initial shape intention. In addition, the user only needs to specify several parameters such as the growth rate g and the time interval T. Our system computes the sequential deformation of a flower during blossom and composes the animation of blossoming. This computation consumes about 1~2 minutes. Fig.1(c) shows several deformed petals of a golden lily in the blossoming process. For the final production of blossom animation, we render the whole scene using locally-deformable pre-computed radiance transfer (LDPRT)[15] and high dynamic range lighting (HDR) techniques implemented in Direct3D 9.0. Fig.7 presents four rendering results.

During the design of the floral blossom, we need to compute the position of each petal at each frame before simulating the continuous petal growth. At each frame, the deformed geometry of the flower model is created in real-time. Although this scheme is suitable for interactive design, a more sophisticated solution is required to generate the flower models of all frames, if the constructed animation is to be integrated into a 3D scene.

6 Conclusions and Future Work

In this paper, we propose a novel floral blossom simulation approach based on a sketch-based interface. The main contributions lie on the simplification of the animation procedure of the floral blossom, and the modulation of the floral animation conforming to biological principles. The resultant system allows for modeling flowers and animating floral blossom intuitively and efficiently.

As future work is concerned, we would like to explore efficient rendering approach for more photo-realistic effects. Another issue is to devise a fast algorithm to detect collision of neighboring petals.

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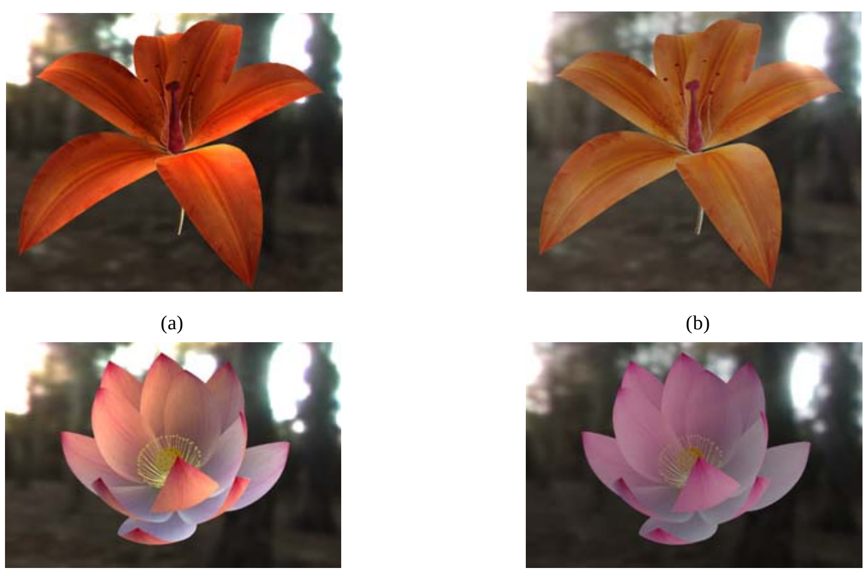

(a) (b)

(c) (d)

Fig.7 Four screen shots of the blossom of two kinds of flowers. (a) The rendering result of a golden lily with LDPRT technique. (b) The rendering result of a golden lily with LDPRT and HDR techniques. (c) The rendering result of a lotus with LDPRT technique. (d) The rendering result of a lotus with LDPRT and HDR techniques

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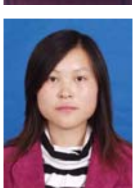

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