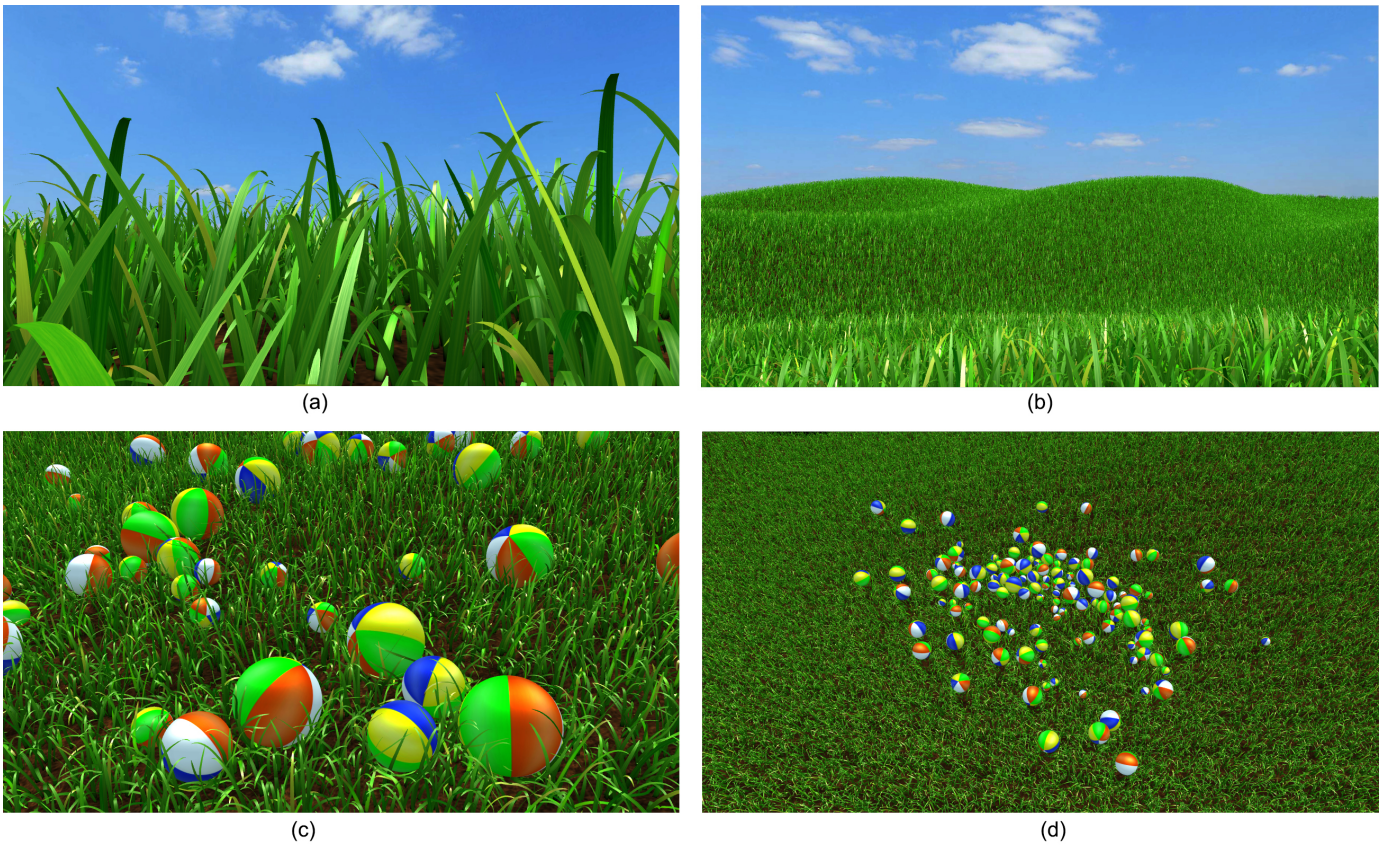
Capturing, Rendering and Simulation for Large Scale Grassland

Zengzhi Fan, Shanghai Jiao Tong University
Bin Sheng, Shanghai Jiao Tong University

Abstract—Grass is a very import element of nature, however creating, rendering and simulating a large scale grassland is not easy due to extremely high computation complexity and large amount of data needed for simulation and rendering. Common sense tells us grass blades so simple that it is not difficult to set up a grass blade model for rendering and simulation, yet there are numerous kinds of grass blades in this world and it's not possible for any system to store all kinds of grass blades in advance. Capturing grass blade with interactive camera can be an intuitive solution for this problem. We provide a method that can capture grass blade shapes with a depth camera, render large scale grassland efficiently and simulate this grassland with individual response for each single blade on the fly.

Index Terms—Grass, Capture, Render, Simulation, GPU



(a) (b) (c) (d)

Fig. 1: Large scale grassland with our method: (a) grass detail in the scene; (b) front view of large scale grassland; (c) grass-ball interaction handling in our system; (d) bird's view of test scene.

1 Introduction

When an object passes through a grassland, every grass blade on the path is pushed aside or run over, and gradually recovers shape afterwards. Individual responses from every single grass blade greatly improve viewers' experience for virtual environment and increase scene fidelity. Obtaining a realistic model for grass blade rendering is not easy since grass blade shape varies a lot. Artists usually ignore the importance of grass blades modeling for their single structure, meanwhile the lack of realistic grass blade model becomes a frequent issue when

creating virtual scenes.

We intend to build a system which is able to capture grass blade from camera, refine grass blade shape and render large scale grassland scene with high quality as well as realistic simulation response to collision with captured model. Depth cameras are especially valued since they are able to provide depth information of any scene, which makes it much easier to rebuild any object or scene. With a depth camera, we are able to capture grass blade shape instantly instead of using a small number of preset shapes. Compared with image-based method, depth-camera-based method is much faster. More importantly, camera can provide human-computer interaction and allow users to adjust capturing results through instant feedback from camera.

We use depth information for background masking, which is difficult and much slower with image-based methods. We extract a blob of grass blades from depth image and calculate the contour of grass blades from extracted blob. A particle-flow method is adopted to partition single blade contour from a cluster blades. According to single blade contour, a vertex matching method is used to calculate blade width and skeleton, which is used to guide the expansion and movement of grass blade in rendering and simulation respectively.

In order to achieve real-time performance of rendering and simulation, every grass blade is modeled as a curve with no more than 64 vertices. We expand this curve to a triangle before rendering. In our system we usually choose 16 as the number of vertices for a single curve to guarantee high rendering and simulation performance. Thus we have to refine the grass shape we capture from camera, and extract the skeleton that could best describe the grass blade's movement, and calculate the expansion width for each vertex of the curve.

Our system is designed to render and simulate a very large scale grassland in which every single grass blade has individual and realistic response to collision. Therefore we apply GPU-based instancing to lower the requirement for memory and bandwidth, and pay simulation costs only when needed. Meanwhile, this is a tile-based rendering and simulation system, no per-tile data is store unless simulation for a specific tile is required. We implement the method introduced by Han et al. [1] to simulate our grass blade and extend the method introduced by Fan et al. [2] to do tile management.

Our main contributions are listed below:

- Interactive grass blade capturing method with depth camera,including skeleton extraction and expansion width calculation
- Blade skeleton refinement according to vertices' movement similarity
- Extension for large scale grassland rendering as well as simulation method with high fidelity, which allow instant shape editing during rendering and simulation

2 Related Work

The most challenging part of grass modeling, rendering and simulation is caused by extremely large quantity. William Reeves and Ricki Blau [3] addressed those challenges in 1985. Works about grass mainly discuss the following three topics: grass modeling, rendering and simulation. Kajiya et al. [4] introduced volumetric textures(texels) for short fur rendering. Texels can used to solve spatial aliasing problem. Neyret extended this work to simulate natural scenes such as realistic grass [5] [6]. Polygons stacks as well as semi-transparent textures were used in implementation of texels [7]. Brook et al [8] improved this method to obtain high rendering performance. Image-based method was used in grass rendering [9]. This method used bidirectional texture function for grass. Boulanger et al. [10] introduced a level-of-detail(LOD) method for grass rendering with realistic dynamic light and shadow effects. In previous works, grass blades were pushed away when interaction between grass blades and objects happens [11]. Spring-mass system was also used to model grass blade and simulate grass-object interaction [12] [13]. A method to modeling withering grass was introduced by Wen et al. [14] using time-varying texels. We adopt the simulation algorithm introduced by Han et al. [1]. This method treated collision as hard constraint, meanwhile treated length, bending and twisting as soft constraints in the iterative solver for grass-object interaction. We employ the rendering and simulation framework introduced by [2]. With this frame work, we are able to perform collision computation on GPU and do grass blade instancing on the fly. We implement our capture method on the basis of this framework to obtain more accurate and diverse grass types.

A number of works for leaf and flora reconstruction have reference value for our method. There are some previous works about using interactive method to generate or reconstruct leaf shapes and tree shapes [15] [16] [17] [18] [19].Quan et al. [20] introduced a method to model plant from a dozen of images. This method could recover plant's shape automatically while relying on user to provide some hints for segmentation. Tan et al. [21] proposed a method to generate 3D trees from images. They populated tree leaves from segmented source images and used shape patterns of visible branches to predict occluded branches. Tree modeling from single image was introduced afterwards [22]. Yan et al. [23] came up with a method for flower reconstruction from a single image, which used a cone fitting scheme to maintains flower shape.Bradley et al. [24] presented a scale technique to compute 3D structure of foliage and extract leaf shapes.

Capturing grass blade with camera has not been explored much, however plenty of researches about hair capture have been conducted. There are some similarities between hair and grass blade for their shapes and movement features. Chai et al. [25] uses single image to do hair modeling, they captured hair style from image and were able to render origin hair style at different angle, with different hair

materials and change hair style . Afterwards, they extended their work through user's high-level knowledge to get more accurate hair that matches image and waa physically real at the same time. By doing it they were able to finish dynamic hair simulation and interactive hair style editing, which made it possible to apply this hair manipulation in video [26]. A structure-aware hair capture method [27] was introduced in 2013, authors adopted a method to generate hair strand segments, set up a connection graph to guarantee hair growth to areas with missed geometry information and connected hair strands with consistent curvature. A method to capture hair using simulated examples was introduced by Hu et al. [28], they used simulated samples as references to generate hair, and this method could be applied with unconstrained and constrained hair. They also came up with a method to capture braided hair style [29]. A data-driven reconstruction method was adopted in this scheme and procedurally generated examples were used to fit captured hair strands. Xu et al. [30] introduced a space-time optimization method to capture dynamic hair. This method could faithfully capture hair strands' shape as well as spatial details.

3 Algorithm Overview

The overview of our algorithm is shown in Figure.2. We employ a depth camera in our system which is able to obtain depth image of target plant. According to this depth image, we are able to extract the contour of grass blades by distance masking method in real time, which is difficult to achieve without depth information. Single blade's contour could be partitioned from a cluster of blades by a particle-flow method [31].

According to contour of grass blade, we calculate blade's skeleton, which is used to describe this blade and is also used in simulation. In vertex shader we expand each knot on the skeleton to form the blade. Expansion widths are calculated from blade's contour and smoothed before rendering.

For skeleton captured from camera, we design an refining algorithm to do simplification. This process is similar to level-of-detail(LOD). Since skeleton knots number is restricted by extremely large amount of grass blades, this refining algorithm could reduce skeleton knots number from over one hundred to 32, 16 or even less, according to knots' movement similarity.

We adopt the GPU instancing scheme used in [2]. We pre-generate a list of grass blade called grass patch. Grass scene is divided into a grid of tiles. Grass blades in each tile are specific number of continuous blades fetched from grass patch. Starting position in grass patch for each tile is calculated by tile's position in the scene. Blade's skeleton is expanded to triangles before rendering. Phong shading model is used in grass blade rendering for the sake of high performance. Subsurface scattering effects is also used in our system to increase fidelity [32]. Tile management guarantee per-blade memory is allocated only when simulation is needed.

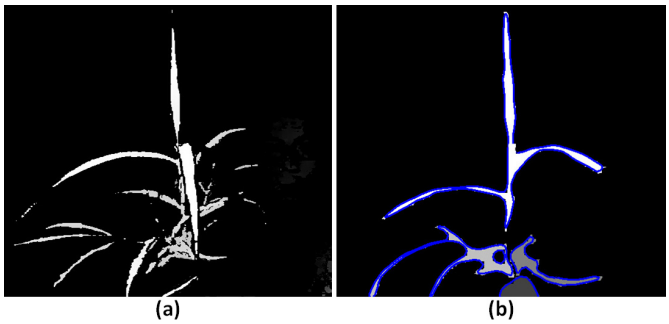


Fig. 3: (a)Depth image and (b)extracted contour

4 Algorithm Details

4.1 Blade Capture

we aim to capture grass blade without manual operations and use capture result in the rendering and simulation system immediately after capturing. Skeleton knots number limits the detail level of our grass blade, however it also requires efficient refining algorithm to convert captured skeleton into appropriate blade model in our system. Motivated by other hair and plant capture methods, we adopt a depth camera to capture grass blade. Depth cameras are deployed in variety of applications and becoming prevailing more than ever, for its advantage to recover shapes and capture movements. With depth camera, we manage to capture grass blade and mask non-grass object on the fly.

Figure3 shows the depth image of a cluster of grass blades and its extracted contour. We just use depth information to mask objects that exceed specified depth to get a blob of blades and then extract edge of the blob. Also canny edge detection can be used to extract contour, however depth value, instead of gray is used to do calculation.

4.2 Single Blade Partition

Individual grass blades are partitioned by a particle-flow method [31]. After getting the contour of grass blades, the center of the contour can be easily calculated. Then the distance between any point on the contour and center point can be measured. Local minimum points of point-distance function imply the intersection points between adjacent blades. Boundary between two intersection points is contour of a single blade. Figure.4 shows the partition result projected in 2D plane.

4.3 Skeleton and Expansion Width Calculation

Given the contour of single blade, we could calculate the blade skeleton. According to our observation on plenty kinds of grass blade ,we suppose that captured blade is symmetrical. Then we could calculate skeleton point by matching symmetrical points on contour. Figure.5 present skeleton calculation according to blade contour. Expansion width for each point of skeleton could also be calculated by symmetrical points' distance.

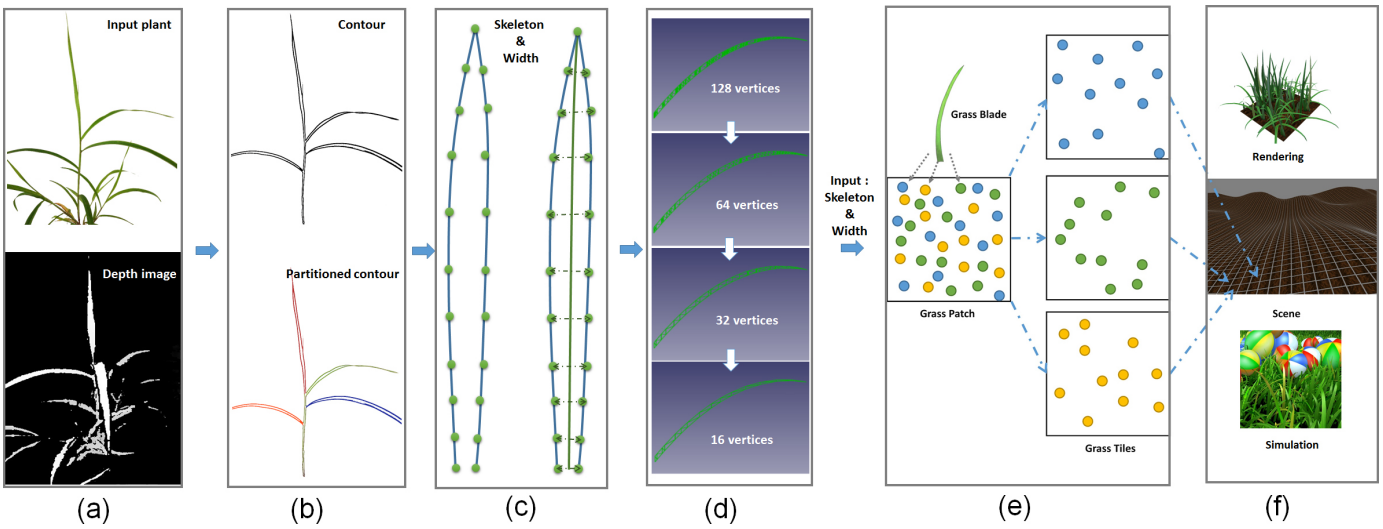


Fig. 2: Overview of system pipeline:(a) a cluster of grass blades and depth depth image captured with camera, those are raw data in our system; (b) extracted contour(top), partitioned contour for single blade marked with different color respectively(bottom);(c) skeleton and expansion width calculation(bottom); (d) skeleton refining process using a idealized blade skeleton with 128 vertices, with different refining levels that reduce skeleton vertices down to 64,32 and 16 vertices; (e) instancing scheme: using refined skeleton to generate a grass patch, every tile refer to a subset of grass blade in the patch, expand skeleton to grass according to expansion width; (f) rendering and simulation.

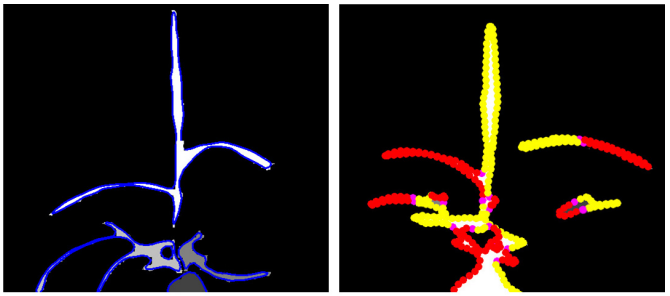


Fig. 4: Single blade partition: Given the (a)contour of a blade cluster,(b)calculate the center point and use particle-flow method to partition each single blade.

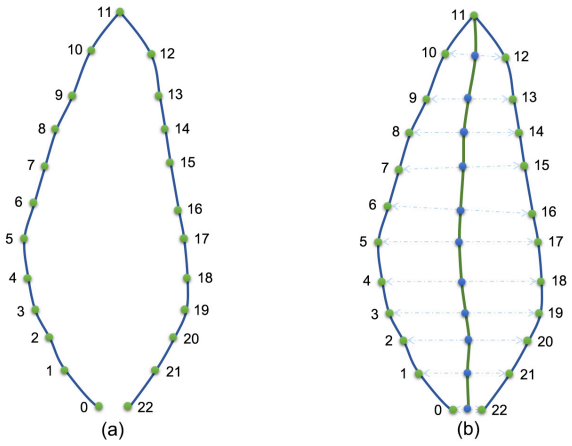


Fig. 5: Skeleton calculation by match symmetrical points on contour.(a) capture single blade contour points, points index increases from bottom left to bottom right;(b) Matching symmetrical points in the contour.

4.4 Skeleton Refining

Having the blade skeleton from contour, it can't be used in our rendering and simulation system for its large number of vertices. Therefore we come up with a skeleton refining method to reduce vertices amount according to vertices' movement similarity.

In our system, we define any two vertices' movement similarity by the distance between them and their movement trends. For any two vertices, the smaller the distance between them is, the more similar they are. And for any two vertices, we could calculate the distance between them at any time. We could acquire the distance of two vertices every a few millisecond. Then we are able to calculate a series distance data for these two vertices. Variance is usually used to describe data stability. If distance variance is low, it means the distance between two vertices is stable. In another word, this indicate that these two vertices moves synchronously. We tend to merge vertices that moves similarly and keep vertices that have distinct movement features. Assume we acquire n frames every a few milliseconds, v_m^n is mth vertex at nth frame, therefore we introduce movement difference of any two vertices as:

$$D(v_1, v_2) = dis(v_1, v_2) \times \mu + var(v_1, v_2) \times (1 - \mu) \quad (1)$$

$$dis(v_1, v_2) = \frac{\sum_{i=0}^{n} d(v_1^i, v_2^i)}{n} \quad (2)$$

$$var(v_1, v_2) = \left(\frac{\sum_{i=0}^{n} d(v_1^i, v_2^i)^2}{n} - \frac{(\sum_{i=0}^{n} d(v_1^i, v_2^i))^2}{n}\right) \quad (3)$$

dis function represents distance factor and var function represents variance factor. μ is proportion factor for distance

and variance, which can be set by user.

We use an iterative algorithm to complete this skeleton refining process. After skeleton calculation, we manage to obtain array of skeleton vertices. We design a greedy algorithm to iteratively merge two adjacent vertices, based on the assumption that if two vertices are the most similar then they should be adjacent vertices in the array. Because distance factor is an very important part in similarity definition, and closer vertices always get lower score for distance factor. This algorithm is illustrated in Algorithm.1.

Algorithm 1 Skeleton Refining

```
//SkeletonVertices = Calculated from captured result
while SkeletonVertices.size() > m do
    DifferenceArr = ∅
    for v_i in SkeletonVertices do
        d_i = D(v_i, v_{i+1})
        DifferenceArr.add(d_i)
    end for

    //Search for minimum d in DifferenceArr
    ind = DifferenceArr.minimum()
    newV = (v_i + v_{i+1})/2

    //Delete old vertices
    DifferenceArr.delete(ind)
    DifferenceArr.delete(ind + 1)

    //Insert new vertex at position i
    DifferenceArr.insert(newV, ind)
end while
```

Figure.6 illustrates a sequence of grass blade with different refining level. Refining level is set by user according to the performance requirement of application and hardware level.

4.5 Rendering and Simulation

According to our captured grass model and refining result, we pre-generate a list of grass blades with some random scaling.We divide the whole scene into tiles. Those blades in the patch are randomly located in a square which has the same size of grass tile in the scene. Each tile contains a subset of continuous blades in the patch. For each grass tile, its offset in the patch is calculated by tile's position coordinate in the scene. With this instancing scheme, we are able to reduce memory use from about 4 GB of 4 M blades to only 24 MB of for a patch of 16384 blades. With this patch, we manage to implement a grassland with rich variance.

We draw one line segment as two degenerate triangles and expand each knot of this line segment at runtime according to expansion width captured through depth camera. Figure.7 illustrates this expansion process. We employ Phong shading along with subsurface scattering effect [32] in our system. In order to avoid a monotone we use a density map in our system. Figure.8 illustrated our

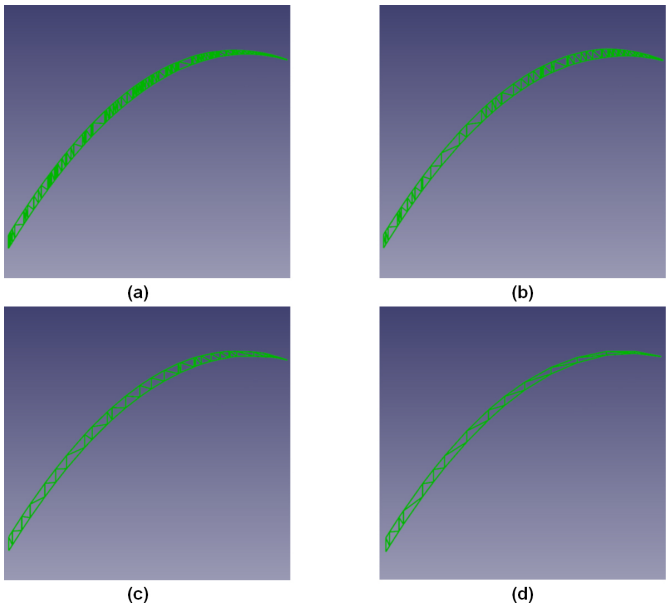


Fig. 6: Skeleton refining process with a sequence of idealized grass blade skeletonin the figure this skeleton is expanded as it is done in vertex shader, at first there is (a) blade skeleton with 128 vertices; after different level of skeleton refining, (b) blade skeleton with 64 vertices; (c) blade skeleton with 32 vertices; (d) blade skeleton with 16 vertices.

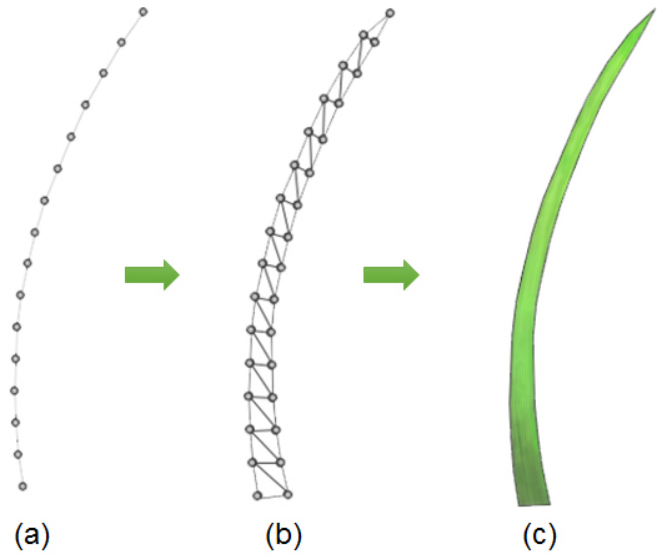


Fig. 7: Blade skeleton expansion:(a) Simulation blade skeleton presented by overlapping vertices; (b) Expanded triangle model from blade skeleton for rendering; (c) shaded result.

density map generated with Perlin noise [33].

In our simulation system, *Bullet* is used to handle collision between ground and other object. We use the simulation method introduced by [1] and tile management scheme introduced by [2]. This simulation scheme is compatible with procedural animation. We are able to simulate millions of grass blades with real-time performance.

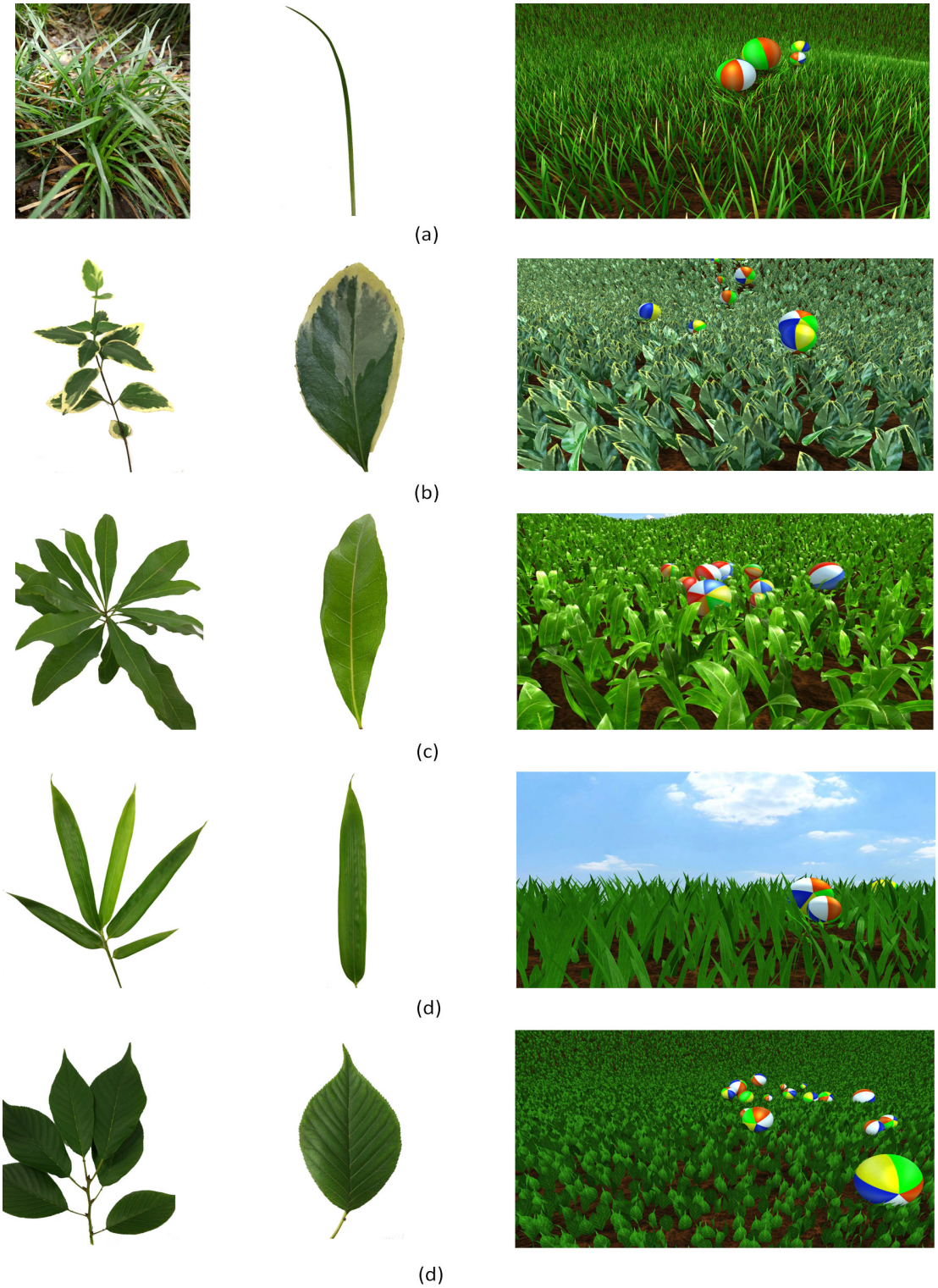


Fig. 9: Experiment results:(a) regular slim and thin grass blade ;(b) blade similar to most leaves, blade edge is quadratic curve like; (c) blade that is slender than the first one, blade edge is still regular (d) bamboo leaf which is thin, its edge is very smooth and flat except for its top and root; (e) leaf with shape variation, it has a very sharp and narrow tip.

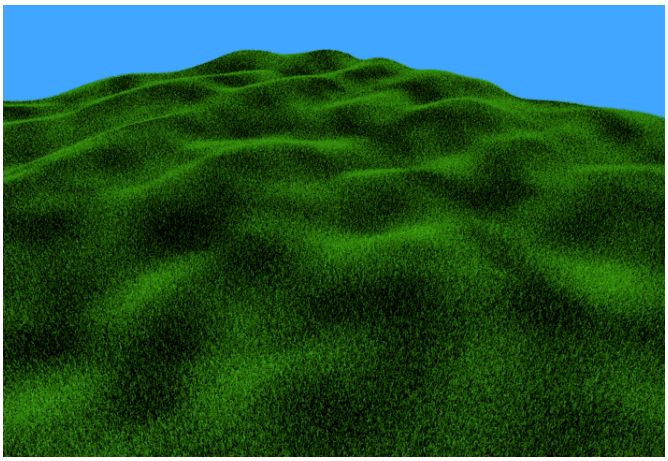


Fig. 8: Blade skeleton expansion:(a) Simulation blade skeleton presented by overlapping vertices; (b) Expanded triangle model from blade skeleton for rendering; (c) shaded result.

5 Implementation and Results

We implemented our system on a PC with Windows 8.1, Intel i5-4460 CPU running at 3.2 GHz and AMD Radeon R9-270 graphic card. 4 times multi-sampling anti-aliasing is used in all experiments to guarantee satisfactory effect.

Our system is evaluated with a variety of grass blades and leaves that can be used for large scale grassland. Our capture algorithm can capture grass blade, partition single blade contour, calculate expansion width and finish skeleton refining at interactive performance. This provide the possibility for user to capture any appropriate kind of grass or leaves and use it for large scale grassland rendering and simulation. This is especially useful for virtual-reality or augmented-reality applications where quick reconstruction of grassland with specific grass blade type is needed.

In Figure.9(a) we choose a regular kind of grass which is slim ,thin and common to find everywhere. In (b) we choose a vine and capture its leaf as grass blade. This blade is like a tree leaf, its blade edge can be described as a quadratic curve. In (c) we choose a cluster of leaves from a shrub. This leaf is longer however its blade edge is still regular and quadratic-curve like. In (d) we choose a cluster of bamboo leaves. Bamboo leave is thin and slim, from the figure we could see that its blade edge is very smooth and flat in the middle and it is hard to be described with simple quadratic curves. In(e) we choose a leaf with variation it the top. It has a very sharp and narrow tip which make it special. Camera captured this feature kept it through our expansion width calculation.

We have tested our algorithm to evaluate its rendering and simulation performance. In our system, we need only one draw call to rendering the whole scene, which greatly reduce CPU overhead. We are able to render a scene of 14926 tiles in 20 ms, in total there are 955264 blades and over 29 million triangles. In table.1, profiling data for simulation demonstrates the effectiveness of our system. Simulation time for a single blade decreases with the increase of simulated tiles as listed in the table. This gives the evidence that our system is suitable to solve the high simulation cost problem caused by extremely large grassland.

Tiles	6	14	150	709
Blades	384	896	9600	45376
Objects	1	2	20	128
Sim time(ms)	0.176	0.183	0.952	4.67
Sim time/Blade (ns)	0.458	0.204	0.099	0.103

TABLE 1: Simulation time data with different activated tiles, objects.

Limitations. Restricted by vertex amount of grass blade, our method has some limitations. First, small vertex amount is not enough to model jagged blades or leaves. Sharp variation in shape definitely need more vertices to remain such features. However, vertex amount is severely restricted by performance requirements, we need to balance vertex amount and performance at the same time. Meanwhile, due to the structure of grass blade we use in our system, we are not able to handle horizontally curly blades. Secondly, since we choose to do instancing before rendering and expand grass blade at runtime, moreover our skeleton calculation by matching points will run into difficulties when dealing with asymmetric grass blades or leaves. Thirdly, the center point calculation of a grass blade cluster requires appropriate pose for camera and blade cluster, causing some accuracy problem if the poses are not proper. Fourthly, depth image capture by depth camera only support a maximum resolution of $640 * 480$ pixels, this will cause some problem when we want to capture some small and thin grass blades. Hopefully this problem would be solved with the development of hardware and popularity of depth camera.

6 Conclusion

In this paper, we present a framework for capturing grass blade with depth camera, expansion width calculation and skeleton extraction. We utilize a increasingly popular depth camera and take advantage of depth information provided by depth camera to accomplish efficient capturing. We extract a blob of blades according to objects' depth range and calculate its edge to obtain a contour. A particle-flow method is used to partition single blade's contour from a cluster of blades. Based on a single blade's contour, we calculate a skeleton by matching symmetrical vertices on the contour and expansion width for each vertices of the skeleton. A skeleton refining process according to vertices' movement similarity is introduced to reduce skeleton vertex number so that it can be used in the rendering and simulation system with acceptable performance. As for rendering, we adopt a GPU-instanced scheme reduce memory usage. A tile management method is employed to pay simulation cost for those tiles only when needed.

Our proposed method concentrate on capturing grass blade shape and refining its structure so that it can be used

in the rendering and simulation method for large scale grassland. We are able to a variety of grass blades. We would like to extend our method to handle more complex blade shapes or capture other kind of plants. Furthermore, our method does not handle grass fracture and deformation. Skeleton and expansion width calculation may get incorrect result with such cases. We plan to handle grass fracture in future works and add support for structurally different vegetation.

In summary, our work demonstrate how interactive capturing method can be developed to model grass blade and use it in rendering and simulation frameworks. This work can be extended to many fields and inspire other capturing and modeling method for plants and other relative objects.

ACKNOWLEDGMENTS

Thank my teammate for helping me with this paper.

REFERENCES

[1] D. Han and T. Harada, "Real-time hair simulation with efficient hair style preservation," *vriphys12-proc*, pp. 45–51, 2012.
[2] Z. Fan, H. Li, K. Hillesland, and B. Sheng, "Simulation and rendering for millions of grass blades," in *Proceedings of the 19th Symposium on Interactive 3D Graphics and Games*. ACM, 2015, pp. 55–60.
[3] W. T. Reeves and R. Blau, "Approximate and probabilistic algorithms for shading and rendering structured particle systems," in *ACM Siggraph Computer Graphics*, vol. 19, no. 3. ACM, 1985, pp. 313–322.
[4] J. T. Kajiya and T. L. Kay, "Rendering fur with three dimensional textures," in *ACM Siggraph Computer Graphics*, vol. 23, no. 3. ACM, 1989, pp. 271–280.
[5] F. Neyret, *Synthesizing verdant landscapes using volumetric textures*. Springer, 1996.
[6] N. Fabrice, "Modeling, animating, and rendering complex scenes using volumetric textures," *Visualization and Computer Graphics, IEEE Transactions on*, vol. 4, no. 1, pp. 55–70, 1998.
[7] A. Meyer and F. Neyret, "Interactive volumetric textures," in *Rendering Techniques 98*. Springer, 1998, pp. 157–168.
[8] B. Bakay, P. Lalonde, and W. Heidrich, "Real-time animated grass," in *Eurographics 2002*, 2002.
[9] M. A. Shah, J. Kontinnen, and S. Pattanaik, "Real-time rendering of realistic-looking grass," in *Proceedings of the 3rd international conference on Computer graphics and interactive techniques in Australasia and South East Asia*. ACM, 2005, pp. 77–82.
[10] K. Boulanger, S. N. Pattanaik, and K. Bouatouch, "Rendering grass in real time with dynamic lighting," *IEEE Computer Graphics and Applications*, no. 1, pp. 32–41, 2009.
[11] S. Guerraz, F. Perbet, D. Raulo, F. Faure, and M.-P. Cani, "A procedural approach to animate interactive natural sceneries," in *Computer Animation and Social Agents, 2003. 16th International Conference on*. IEEE, 2003, pp. 73–78.
[12] K. Chen and H. Johan, "Real-time continuum grass," in *Virtual Reality Conference (VR), 2010 IEEE*. IEEE, 2010, pp. 227–234.
[13] N. Hempe, J. Rossmann, and B. Sondermann, "Generation and rendering of interactive ground vegetation for real-time testing and validation of computer vision algorithms," 2013.
[14] W. Wu, P.-A. Heng, E. Wu *et al.*, "Using time-varying texels to simulate withering grassland," *Computer Graphics and Applications, IEEE*, vol. 32, no. 1, pp. 78–86, 2012.
[15] L. Mündermann, P. MacMurchy, J. Pivovarov, and P. Prusinkiewicz, "Modeling lobed leaves," in *Computer Graphics International, 2003. Proceedings*. IEEE, 2003, pp. 60–65.
[16] M. Okabe, S. Owada, and T. Igarash, "Interactive design of botanical trees using freehand sketches and example-based editing," in *Computer Graphics Forum*, vol. 24, no. 3. Wiley Online Library, 2005, pp. 487–496.
[17] F. Anastacio, M. C. Sousa, F. Samavati, and J. A. Jorge, "Modeling plant structures using concept sketches," in *Proceedings of the 4th international symposium on Non-photorealistic animation and rendering*. ACM, 2006, pp. 105–113.
[18] X. Chen, B. Neubert, Y.-Q. Xu, O. Deussen, and S. B. Kang, *Sketch-based tree modeling using Markov random field*. ACM, 2008, vol. 27, no. 5.
[19] S. Pirk, O. Stava, J. Kratt, M. A. Massih Said, B. Neubert, R. Mech, B. Benes, and O. Deussen, "Plastic trees: interactive self-adapting botanical tree models," 2012.
[20] L. Quan, P. Tan, G. Zeng, L. Yuan, J. Wang, and S. B. Kang, "Image-based plant modeling," in *ACM Transactions on Graphics (TOG)*, vol. 25, no. 3. ACM, 2006, pp. 599–604.
[21] P. Tan, G. Zeng, J. Wang, S. B. Kang, and L. Quan, "Image-based tree modeling," in *ACM Transactions on Graphics (TOG)*, vol. 26, no. 3. ACM, 2007, p. 87.
[22] P. Tan, T. Fang, J. Xiao, P. Zhao, and L. Quan, "Single image tree modeling," *ACM Transactions on Graphics (TOG)*, vol. 27, no. 5, p. 108, 2008.
[23] F. Yan, M. Gong, D. Cohen-Or, O. Deussen, and B. Chen, "Flower reconstruction from a single photo," in *Computer Graphics Forum*, vol. 33, no. 2. Wiley Online Library, 2014, pp. 439–447.
[24] D. Bradley, D. Nowrouzezahrai, and P. Beardsley, "Image-based reconstruction and synthesis of dense foliage," *ACM Transactions on Graphics (TOG)*, vol. 32, no. 4, p. 74, 2013.
[25] M. Chai, L. Wang, Y. Weng, Y. Yu, B. Guo, and K. Zhou, "Single-view hair modeling for portrait manipulation," *ACM Transactions on Graphics (TOG)*, vol. 31, no. 4, p. 116, 2012.
[26] M. Chai, L. Wang, Y. Weng, X. Jin, and K. Zhou, "Dynamic hair manipulation in images and videos," *ACM Transactions on Graphics (TOG)*, vol. 32, no. 4, p. 75, 2013.
[27] L. Luo, H. Li, and S. Rusinkiewicz, "Structure-aware hair capture," *ACM Transactions on Graphics (TOG)*, vol. 32, no. 4, p. 76, 2013.
[28] L. Hu, C. Ma, L. Luo, and H. Li, "Robust hair capture using simulated examples," *ACM Transactions on Graphics (TOG)*, vol. 33, no. 4, p. 126, 2014.
[29] L. Hu, C. Ma, L. Luo, L.-Y. Wei, and H. Li, "Capturing braided hairstyles," *ACM Transactions on Graphics (TOG)*, vol. 33, no. 6, p. 225, 2014.
[30] Z. Xu, H.-T. Wu, L. Wang, C. Zheng, X. Tong, and Y. Qi, "Dynamic hair capture using spacetime optimization," *To appear in ACM TOG*, vol. 33, p. 6, 2014.
[31] B. Neubert, T. Franken, and O. Deussen, "Approximate image-based tree-modeling using particle flows," *ACM Transactions on Graphics (TOG)*, vol. 26, no. 3, p. 88, 2007.
[32] T. Sousa, "Vegetation procedural animation and shading in crysis," *GPU Gems*, vol. 3, pp. 373–385, 2007.
[33] K. Perlin, "An image synthesizer," *ACM Siggraph Computer Graphics*, vol. 19, no. 3, pp. 287–296, 1985.

Zengzhi Fan Biography text here.

Bin Sheng Biography text here.