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A SURVEY ON SMOOTHING SUBDIVISION SURFACES METHODS

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Abstract: This paper displays a study of the work done in demonstrating existing subdivision schemes and compares them. The advantages and disadvantages of these approaches are mentioned along with the methodology involved. The paper also presents the scope of subdivision surfaces in the near future and what are the main steps undertaken so that the demands in the field of animation can be met. The main objective of this paper is to present a brief introduction to the theory and algorithms correlated to subdivision surfaces from basic facts about subdivision to more recent research developments.

Keywords: control mesh, subdivision, refinement, spline surfaces, Catmull-Clark surfaces, Doo-Sabin, ordinary vertices, extraordinary vertices.

I. Introduction

In the recent few years, subdivision surfaces [1] are being more widely used, the main driving force is that they overcome some of the major disadvantages of the existing tools used in the field of graphics and multimedia. They are used to obtain a generalization of spline surfaces [2]. The main advantage of using subdivision surfaces is that the algorithms associated with it are much easier to implement than some of the classical tools used (NURBS)[3]. They can easily handle the meshes of any given topology and they provide smooth surfaces. The subdivision surfaces are defined in a recursive manner. The initial step includes any arbitrary mesh which is the initial mesh. On this initial mesh, refinement techniques are applied. Depending on the type of subdivision either new vertices or faces will be created. Catmull-Clark surfaces is an example of subdivision surfaces where the splitting of each face takes place and an example where the vertices are split is Doo-Sabin method. In this process, sometimes the position of the original vertices might be altered. The placement of the new vertices is calculated with the position of the original vertices. The output obtained will be a mesh which will have more number of faces than the original mesh. This is an iterative process and can be applied more than one time. However, in practical use it is applied only up to a certain limit. There can be two main types of schemes that can be used for the process of refinement. These are interpolating and approximating [4]. Better smoothness can be obtained in approximating schemes which can adjust the placement of the original vertices in the control mesh. Whereas in interpolating schemes the placement of the original vertices must match the vertices in the control mesh. The third kind of subdivision surfaces include the subdivision of polygon surfaces where the control mesh is either divided into triangles of quadrilaterals. Examples of approximating schemes include Catmull-Clark [5], $\sqrt{3}$ subdivision [6], Mid-Edge subdivision [7], Loop, Doo-Sabin [8]. Butterfly [9], Midedge [10] are examples of interpolating schemes. Out of these schemes the worst quality is given by Butterfly scheme in which the original mesh is interpolated. It can be concluded that the quality decreases as the interpolation factor increases. But both Doo-Sabin and the butterfly scheme can give the shape of the object more clearly as compared to the other schemes. Loop and Catmull-Clark can provide the best results with all most all the applications and can be implemented more efficiently.

II. Basics of Subdivision

There are many criteria's based on which the subdivision schemes can be grouped. These groupings can be done with respect to the position of the control points, whether the faces are quadrilateral [11] or triangular [12] if the vertices are split or the faces. Primal type means that the faces are split and dual type means that the vertices are split. In case of a triangular mesh, ordinary vertices are a set of vertices that have 6 as the valence in the interior and the outer valence is computed to be 4. Whereas, in case of quadrilateral meshes, the vertices which have a valence 4 in the interior and 3 in the exterior are known as ordinary vertices. All the vertices except the ordinary vertices are known as extraordinary vertices.

III. Various Approaches on Smoothing Subdivision

Aaron Lee [13] has put forward a new approach where the original control mesh created is transformed into a smooth domain surface and then further into displaced subdivision surface. This approach overcomes a major disadvantage which is faced when using a triangular control mesh. Control meshes as shown in figure 1 are very expensive to use in terms of their memory usage, since it stores information regarding the coordinates, the irregular connectivity of the faces, texture parametrization.

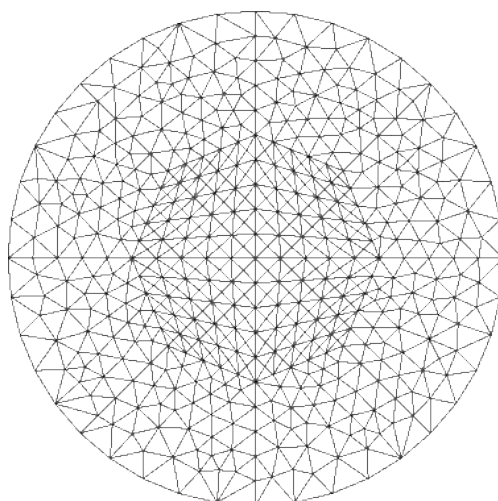


Figure 1

So this approach proposed can be used as an alternative. One of the major advantages of using this approach is that the control mesh in this method is defined in such a way that the connectivity between the mesh is much simpler than that of the originally used mesh. The other major advantage is that the parametrisation need not be stored separately, since it is inherited from one of the intermediate steps (smooth domain surface). The main idea behind this approach is that smooth surfaces can be represented without the requirement of the control point constraints so, using subdivision surfaces we can define domain surface. The displacement function is defined using the concept of subdivision on the surface. These scalar displacements are then using a regular mesh stored to form the displaced subdivision surface. The advantages of this model include Compression, Editing, Scalability, Animation and Rendering. The original mesh is first simplified to attain an initial control mesh. This simplification is carried out by using the Edge collapse transformations [14]. Then the control mesh vertices are optimized globally so that the domain surface fits the original mesh more accurately. Until they cross the first work test the dislodging map by shooting beams along the area surface normal. At the beam convergence focuses, figure the marked removal, and alternatively test other appearance properties like surface shading.

We improve the first work utilizing a succession of edge fall changes organized by quadric blunder metric of Garland and Heckbert [15]. Keeping in mind the end goal to deliver a decent space surface, we limit a portion of the competitor edge breakdown. The fundamental goal is that the subsequent area surface ought to have the capacity to express the first work utilizing the scalar dislodging map. Our main attitude is to assure the originality of the space of normal on the area surface of the first work is maintained. The MAPS plan as shown in figure 2 is utilized to track parameterizations of all unique vertices on the work streamlined in order to keep up an effective correspondence between the first work and the disentangled work. (At the point when an edge is giving way, the parametrizations of focuses in the area is overhauled utilizing a nearby 1-to-1 delineating the subsequent neighbourhood.)

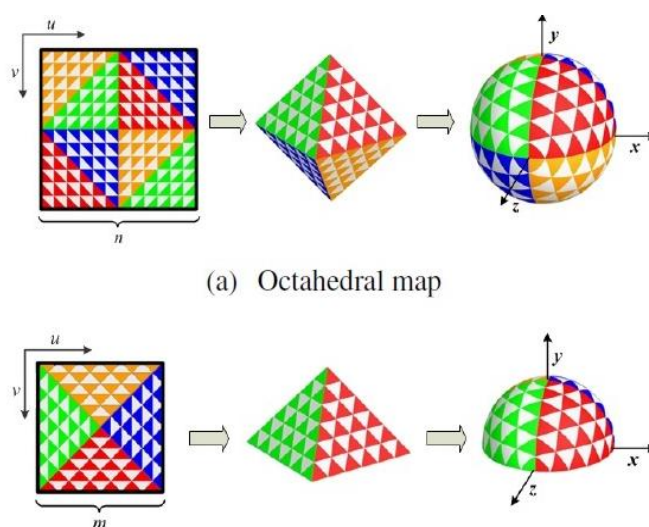


Figure 2

For every competitor edge crumple change, we look at the work neighbourhood that would come about. For every face in the 1-ring neighbourhood, the 3 subdivision surface normal at the vertices are accumulated and circular triangle on the Gauss circle are framed. At that point, we test whether this round triangle encases the normal of

the first work vertices parameterized utilizing MAPS. In the event that this test falls flat on any face in the 1-ring, the edge crumple change is prohibited. To permit disentanglement to continue advance, we have thought that it was helpful to widen each circular triangle by pushing its three vertices an extra 45 degrees far from its engraved focus. If the valence is greater than 8 then we do not allow the edge collapse so that we can avoid any kind of undesirable undulations. Then we have to carry out the second step, which is the optimization of the domain surface area. For this, we first sample a dense set of points and then minimize their squared distances to the subdivision surfaces. This nonlinear enhancement issue is approximated by iteratively anticipating the focuses onto the surface and unravelling for the most exact surface while settling those parameterizations. We apply k ventures of Loop subdivision to the control work. At each of these subdivided vertices, we register the utmost position and typical of the area surface. We look to process the marked separation from the restrict indicate the first surface along the ordinary. The coordinated line shaped by the point and typical is met with the first surface, utilizing a spatial chain of importance for effectiveness. We neglect any crossing point if the converged surface is arranged in the wrong course as for the coordinated line. In the event that different crossing point focuses remain, we pick the one nearest to the space surface. Close surface limits, there is the issue that the area surface may stretch out past the limit of the first surface, in which case the beam does not cross any valuable part of the first surface. (We identify this utilizing a greatest separation limit in view of the work measure.) For this situation, the surface should be left indistinct, i.e. trimmed to the point by point limit of the first work. One approach is store an extraordinary illicit esteem into the removal delineates. Rather, we locate the nearest unique triangle to the subdivided vertex, and converge the beam with the plane containing that triangle. Exact surface trimming can be accomplished utilizing an alpha veil as a part of the surface shading picture, however we have not yet executed this. For magnification, we can apply the mask used for subdivision in displacement field and the domain surface. To collect samples, we can carry out our computation at any level l , such that $l < k$ and the displacement level as $l+1$. This paper gives us a significant amount of savings in terms of storage when compared to the traditional mesh compression schemes.

In the research carried out by Leif Kobbelt [16] a new subdivision method, $\sqrt{3}$ subdivision method is explained. In the $\sqrt{3}$ method, as compared to the mostly used dyadic split operation the topological refinement takes place in a slower manner. Instead of increasing the number of triangles by 4 in every step, now the number of triangles is increased by 3. The existing method of two dyadic splits will result the original edge being divided into four halves whereas with the application of this method twice we obtain the result that the original edge is divided uniformly into 3 halves. The most boundless approach to consistently refine a given triangle mesh is the dyadic split which bi-organizations every one of the edges by embedding another vertex between each nearby match of old ones. This kind of part has the beneficial outcome that all recently embedded vertices have valence six and the valences of the old vertices does not change. In the wake of applying the dyadic split a few times, the refined networks M_k have a semi-consistent structure since the rehashed 1-to-4 refinement replaces each triangle of the first work by a standard fix with 4^k triangles. A direct speculation of the dyadic split is the n -adic split where each edge is subdivided into n portions and thus every unique face is part into n^2 sub-triangles. Figure 3 shows the working of the above method.

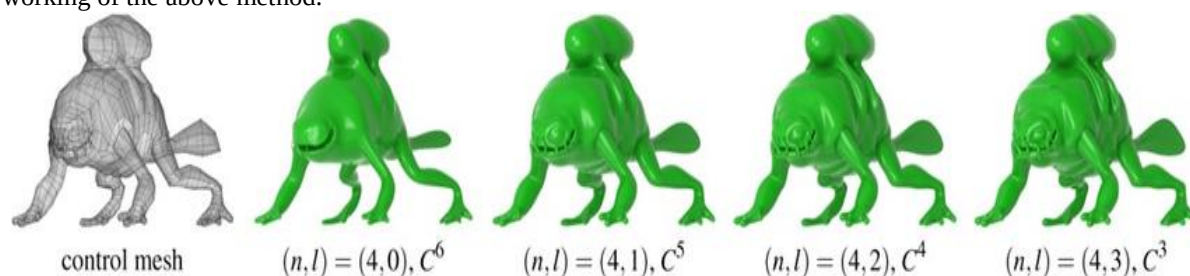


Figure 3

The reason subdivision plans are for the most part in light of the dyadic split that lone requires two smoothing rules: one for the old vertices and one for the new ones. To implement the $\sqrt{3}$ subdivision method, a new vertex is added to the centre of every triangle to carry out the 1-to-3 split on the original mesh M_0 . New vertices are connected to the old ones by the three new edges. The original edge is then flipped so as to maintain the valence of the mesh vertices. The output of this method would be a refined and rotated uniform grid. If this is applied twice then every triangle would be split into 9 sub triangles. The valences of all the newly inserted vertices would be exactly six. The valency of the original vertices is not affected much. The major advantage of this is that it is easy to implement and that we obtain no inconsistent intermediate results. To carry out the new scheme, we need two smoothing techniques, one to place the newly created vertices and the other to relax the original vertices.

Velho [17] shows another plan for subdivision surfaces in view of four-directional lattices with Quasi 4-8 subdivision. It consolidates geometry-touchy refinement with convolution smoothing. The plan has a straightforward, efficient usage and produces smooth all around moulded cross sections. 4-8 meshes are a form of triangular meshes with the condition that each of the vertices will have a valency of either 4 or 8. Further, all the

internal vertices having valency 8 should be surrounded by a ring of alternating vertices having valency 4 and 8. In addition to that all the internal vertices having valency 4 should be surrounded by vertices having valency 8. The interleaved refinement technique is fundamentally the same as the ordinary one. The distinction is that progression (1) parts just edges interfacing valence 8 vertices, and step (2) subdivides confronts in two, as needs be. The consistency of the work ensures that only one edge cuts up in every face. The disadvantage in the method is that it is not applicable on an arbitrary surface. To overcome this refinement operator is defined in the paper from which we can obtain a 4-8 quasi mesh from any arbitrary mesh. In addition to this, a smoothening operator is also defined. It is implemented by a series of averaging operations. In the first pass, the new vertices are calculated by taking out the average of the neighbouring four vertices. The values of the old vertices are updated in the second pass. The main advantage of the paper is that both refining and smoothing operations are implemented together.

Tony DE Rosé, Michael Kass and Tien Truong [18] performed analysis to describe the various steps that have been undertaken so that the requirements in the field of subdivision surfaces can be met in animation. To implement this Catmull-Clark surfaces are used because in this quadrilaterals are formed instead of triangles. When compared, we can conclude that quadrilaterals are more efficient in capturing symmetries. We start with an arbitrary polyhedron mesh M^0 , which is assumed to have n faces. These n faces are split into n quadrilaterals which gives us the mesh M^1 . On repeated implementation of this concept, we obtain the limit surface. Then the paper focuses on the generalization of the surfaces so that the sharpness of the mesh can be controlled by crease. Further, the concept of energy functional was also mentioned in the paper to specify the basic properties of the material can be specified. To overcome collisions each geometric element which includes faces, edges etc. can be checked against each element. But, if we have N elements then the time required will be N^2 . To overcome this difficulty, two approaches are mentioned which are 2D surface based data structure and 3D volume based data structure. If the connectivity of the surface does not change then 2D surface based data structures are preferred. The time is reduced and further the local refinement is also possible in this approach.

Denis Zorin and Peter Schröder [19] implement the smoothing of surfaces by alternating primal and dual subdivision methods. The main concepts used to implement this include vertex split, control point replication and repeated averaging. If we assume that each vertex v has some valence k , then we are required to split the vertex v into k vertices such that there is a vertex for each possible face. Then the assignment of control points of the new vertices takes place by initializing them to the control point of the vertex whose split created the new vertices. Then, for each of the newly created vertices a new face is created. Up to nine averaging steps are implemented here. Starting from Midpoint subdivision, Doo-Sabin, Catmull-Clark, Biquadratic and so on can take place. The approach is easy in terms of implementation and B-splines can be constructed easily. The main difficulty with this method is that it cannot be used when we have surfaces irregular elements (vertices, edges, faces) and the output in terms of the smoothness which will be obtained when the number of averaging steps are increased furthermore is undetermined.

A new method was suggested by S. Schaefer, J. Hakenberg, J. Warren [20] to perform subdivision of tetrahedral meshes. The main advantage of this approach is that it is easier to implement as compared to the existing method. The process of smoothing is repeated. The initial mesh that is the control mesh is splitted into four tetrahedron and an octahedron using linear subdivision. To reposition each vertex, a smoothing pass is performed over this tetrahedral/octahedral mesh. When the subdivision is performed over a number of times on the original mesh, the output mesh obtained is called the refined mesh. In the creation of this refined mesh, some new vertices are inserted. Using the original vertices these new vertices are expressed as a convex combination. Then the barycentric coordinates of the vertices in the mesh to be deformed are calculated.

IV. Conclusion

The main objective of the paper was to analyse the various subdivision methods, its working and its advantages and disadvantages from various research papers published related to the above topic. Subdivision surfaces are finding increased usage primarily because all the algorithms that are associated with the concept are easy to implement. There are certain areas which require further more study and it has a lot of future scope. While there was a fast advance in subdivision hypothesis in the late 90s, few inquiries were determined indisputably. While smoothness criteria exist and are entrenched, applying these criteria stays troublesome, particularly for parametric groups of subdivision plans and requires broad calculations.

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