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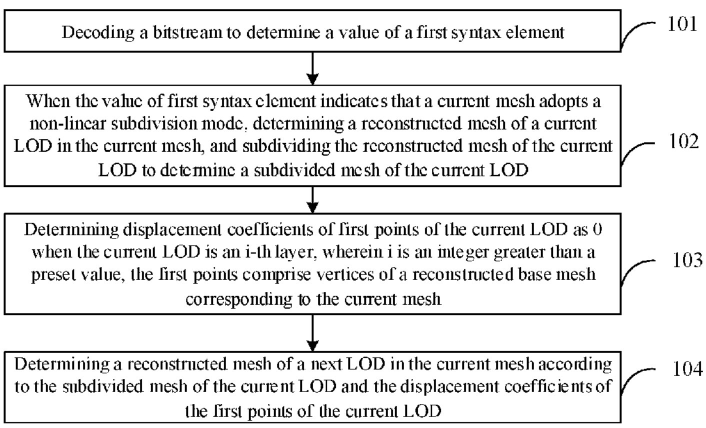

FIG. 16

(57) Abstract: A codec method, a bitstream, encoder, decoder, storage medium and program product are disclosed. The method includes: decoding a bitstream to determine a value of the first syntax element; when the value of first syntax element indicates that a current mesh adopts a non-linear subdivision mode, determining a reconstructed mesh of a current LOD in the current mesh, and subdividing the reconstructed mesh of the current LOD to determine a subdivided mesh of the current LOD; determining displacement coefficients of first points of the current LOD as 0 when the current LOD is an i-th LOD, wherein i is an integer greater than a preset value, the first points comprise vertices of a reconstructed base mesh corresponding to the current mesh; and determining a reconstructed mesh of a next LOD in the current mesh according to the subdivided mesh of the current LOD and the displacement coefficients of the first points of the current LOD.

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ENCODING METHOD, DECODING METHOD, BITSTREAM, ENCODER, DECODER, MEDIUM AND PROGRAM PRODUCT

CROSS-REFERENCE OF RELATED APPLICATION

[0001] This application is based on and claims priority from U.S. patent application No. 63/521,327 filed on June 15, 2021, the present disclosure of which is hereby incorporated by reference in its entirety.

TECHNICAL FIELD

[0002] The present disclosure relates to the technical field of video codec, and in particular, to an encoding method, decoding method, bitstream, encoder, decoder, storage medium and program product.

BACKGROUND

[0003] In standard reference software for Dynamic Mesh Coding (DMC) provided by Moving Picture Experts Group (MPEG), when encoding and decoding geometry information of a mesh, the following operations are performed. First, an original mesh is preprocessed to get a base mesh. Here, the base mesh is encoded in a generic encoding method (e.g., "edgebreaker"). Then, the base mesh is subdivided to obtain a subdivided mesh. Next, displacement coefficients are determined based on a difference between the subdivided mesh and an approximate point of the original mesh. Finally, the displacement coefficients are packaged into a two-dimensional image and encoded in a lossless video coding method such as High Efficiency Video Coding (HEVC).

[0004] However, in the process of encoding and decoding the geometry information of the mesh, there is redundancy in encoding displacement coefficients due to incomplete consideration of the subdivision process, which reduces the efficiency of encoding and decoding.

SUMMARY

[0005] The present disclosure provides an encoding method, decoding method, bitstream, encoder, decoder, storage medium and program product, which can reduce encoded bits of displacement coefficients, thereby improving the codec efficiency.

[0006] The technical solution of the present disclosure may be implemented as follows.

[0007] In a first aspect, there is provided a decoding method applied to a decoder. The decoding method including: decoding a bitstream to determine a value of a first syntax element; when the value of first syntax element indicates that a current mesh adopts a non-linear subdivision mode, determining a reconstructed mesh of a current LOD in the current mesh, and subdividing the reconstructed mesh of the current LOD to determine a subdivided mesh of the current LOD; determining displacement coefficients of first points of the current LOD as 0 when the current LOD is an i-th LOD, wherein i is an integer greater than a preset value, the first points include vertices of a reconstructed base mesh corresponding to the current mesh; and determining a reconstructed mesh of a next LOD in the current mesh according to the subdivided mesh of the current LOD and the displacement coefficients of the first points of the current LOD.

[0008] In a second aspect, there is provided an encoding method applied to an encoder. The encoding method including: when a current mesh adopts a nonlinear subdivision mode, determining a value of a first syntax element, writing the first syntax element into a bitstream, determining a reconstructed mesh of a current LOD in the current mesh, and subdividing the reconstructed mesh of the current LOD to determine a subdivided mesh of the current LOD; when the current LOD is an i-th LOD, determining displacement coefficients of first points of the current LOD as 0, wherein i is an integer greater than a preset value, and the first points include vertices of a reconstructed base mesh corresponding to the current mesh; and determining a reconstructed mesh of a next LOD in the current mesh according to the subdivided mesh of the current LOD and the displacement coefficients of the first points of the current LOD.

[0009] In a third aspect, there is provided a bitstream generated by bit encoding according to information to be encoded, wherein the information to be encoded includes at least one of: a base mesh of a current mesh, displacement coefficients of at least one LOD of the current mesh, quantization parameters of the at least one LOD of the current mesh, a quantization parameter increment of the at least one LOD of the current mesh, a value of a first syntax element, a value of a second syntax element, and a value of a third syntax element.

[0010] In a fourth aspect, there is provided an encoder, including: a determining unit configured to: when a current mesh adopts a nonlinear subdivision mode, determine a value of a first syntax element, write the first syntax element into a bitstream, determine a reconstructed mesh of a current LOD in the current mesh, and subdivide the reconstructed mesh of the current LOD to determine a subdivided mesh of the current LOD; when the current LOD is an i-th LOD, determine displacement coefficients of first points of the current LOD as 0, wherein i is an integer greater than a preset value, and the first points include vertices of a reconstructed base mesh corresponding to the current mesh; and determine a reconstructed mesh of a next LOD in the current mesh according to the subdivided mesh of the current LOD and the displacement coefficients of the first points of the current LOD.

[0011] In a fifth aspect, there is provided an encoder, including: a memory for storing a computer program executable by a processor; the processor for executing the encoding method according to the method of the second aspect.

[0012] In a sixth aspect, there is provided a decoder, including: a determining unit configured to: decode a bitstream to determine a value of a first syntax element; when the value of the first syntax element indicates that a current mesh adopts a non-linear subdivision mode, determine a reconstructed mesh of a current LOD in the current mesh, and subdivide the reconstructed mesh of the current LOD to determine a subdivided mesh of the current LOD; determine displacement coefficients of first points of the current LOD as 0 when the current LOD is an i-th LOD, wherein i is an integer greater than a preset value, the first points include vertices of a reconstructed base mesh corresponding to the current mesh; and determine a reconstructed mesh of a next LOD in the current mesh according to the subdivided mesh of the current LOD and the displacement coefficients of the first points of the current LOD.

[0013] In a seventh aspect, there is provided a decoder including: a memory for storing a computer program executable by a processor; the processor for executing the method of the first aspect when running the computer program.

[0014] In an eighth aspect, there is provided a computer-readable storage medium having stored thereon a computer program that when executed by at least one processor, implements the method of the first aspect or the method of the second aspect.

[0015] In a ninth aspect, there is provided a computer program product including a computer program or instruction, wherein the computer program or instruction, when executed by at least one processor, implements the method of the first aspect or the method of the second aspect.

[0016] Provided are an encoding method, decoding method, bitstream, encoder, decoder, storage medium, and program product. At the decoding side, a bitstream is decoded to determine a value of a first syntax element; when the value of first syntax element indicates that a current mesh adopts a non-linear subdivision mode, a reconstructed mesh of a current LOD in the current mesh is determined, and the reconstructed mesh of the current LOD is subdivided to determine a subdivided mesh of the current LOD; displacement coefficients of first points of the current LOD are determined as 0 when the current LOD is an i-th LOD, wherein i is an integer greater than a preset value, the first points include vertices of a reconstructed base mesh corresponding to the current mesh; and a reconstructed mesh of a next LOD in the current mesh is determined according to the subdivided mesh of the current LOD and the displacement coefficients of the first points of the current LOD. At the encoder side, when a current mesh adopts a nonlinear subdivision mode, a value of a first syntax element is determined, the first syntax element is written into a bitstream, a reconstructed mesh of a current LOD in the current mesh is determined, and the reconstructed mesh of the current LOD is subdivided to determine a subdivided mesh of the current LOD; when the current LOD is an i-th LOD, displacement coefficients of first points of the current LOD are determined as 0, wherein i is an integer greater than a preset value, and the first points include vertices of a reconstructed base mesh corresponding to the current mesh; and a reconstructed mesh of a next LOD in the current mesh is determined according to the subdivided mesh of the current LOD and the displacement coefficients of the first points of the current LOD. That is, in the embodiments of the present disclosure, by adding a first syntax element indicating that the current mesh adopts a non-linear subdivision method, the displacement coefficients close to the vertices in the base layer can be removed from the displacement list in the encoding stage, and the displacement coefficients close to the vertices in the base layer is inferred to be equal to 0 in the decoding stage. Therefore, in the subsequent process of recursively applying the displacement coefficients to the previously reconstructed Levels of Details (LODs), the redundancy problem of the displacement coefficients at the higher levels can be improved, the encoded bits of the displacement coefficients can be reduced, and the encoding and decoding efficiency can be improved.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] The drawings that are incorporated in and form part of the Description, illustrate embodiments in accordance with the present disclosure, and are used together with the specification to explain the principles of the present disclosure, in the drawings:

[0018] FIG. 1 is a flowchart of a geometry coding;

[0019] FIG. 2 is a schematic diagram of a generation process of displacement components;

[0020] FIG. 3 is a decomposed schematic diagram of displacement components in a local coordinate system;

[0021] FIG. 4 is a schematic diagram of a recursive subdivision using displacements in a normal direction perpendicular to a surface;

[0022] FIG. 5 is a schematic diagram of a mesh subdivision;

[0023] FIG. 6 is a schematic diagram of a mesh subdivision result with 2 LODs and one-dimensional displacements;

[0024] FIG. 7 is a schematic diagram of an encoding process of a parameterized mesh;

[0025] FIG. 8 is a schematic diagram of geometry information in a mesh frame;

[0026] FIG. 9 is a surface diagram of a mesh consisting of four vertices and three faces;

[0027] FIG. 10 is a schematic diagram of a data structure of a mesh consisting of four vertices and three faces;

[0028] FIG. 11 is a schematic diagram of a data structure of a parameterized mesh having an attribute texture map;

[0029] FIG. 12 is a schematic diagram of a mesh with attribute mapping characteristics consisting of four vertices and three triangular faces;

[0030] FIG. 13A is a schematic diagram of a manifold mesh;

[0031] FIG. 13B is a schematic diagram of a non-manifold mesh;

[0032] FIG. 14 is a mapping diagram of displacement components;

[0033] FIG. 15A is a schematic diagram of a displacement component packing of a two-dimensional image;

[0034] FIG. 15B is a schematic diagram of displacement component packing of another two-dimensional image;

[0035] FIG. 16 is a first flowchart of a decoding method provided by an embodiment of the present disclosure;

[0036] FIG. 17 is a second flowchart of a decoding method provided in an embodiment of the present disclosure;

[0037] FIG. 18 is a third flowchart of a decoding method provided by an embodiment of the present disclosure;

[0038] FIG. 19 is a fourth flowchart of a decoding method provided in an embodiment of the present disclosure;

[0039] FIG. 20 is a schematic diagram of a recursive subdivision result of a mesh provided by an embodiment of the present disclosure;

[0040] FIG. 21 is a detailed flowchart of a recursive subdivision provided by an embodiment of the present disclosure;

[0041] FIG. 22 is a schematic diagram of a non-linear subdivision result of a mesh provided by an embodiment of the present disclosure;

[0042] FIG. 23 is a detailed flowchart of a non-linear subdivision provided by an embodiment of the present disclosure;

[0043] FIG. 24 is a fifth flowchart of a decoding method provided by an embodiment of the present disclosure;

[0044] FIG. 25 is a first flowchart of an encoding method provided by an embodiment of the present disclosure;

[0045] FIG. 26 is a second flowchart of an encoding method provided by an embodiment of the present disclosure;

[0046] FIG. 27 is a third flowchart of an encoding method provided by an embodiment of the present disclosure;

[0047] FIG. 28 is a fourth flowchart of an encoding method provided in an embodiment of the present disclosure;

[0048] FIG. 29A is a schematic diagram of a packing mode of displacement coefficients in a two-dimensional image provided by an embodiment of the present disclosure;

[0049] FIG. 29B is a schematic diagram of another packing mode of another displacement coefficient in a two-dimensional image provided by an embodiment of the present disclosure;

[0050] FIG. 30 is a schematic diagram of an encoder provided in an embodiment of the present disclosure;

[0051] FIG. 31 is a schematic diagram of a specific hardware structure of an encoder provided in an embodiment of the present disclosure;

[0052] FIG. 32 is a schematic diagram of a structure of a decoder provided in an embodiment of the present disclosure;

[0053] FIG. 33 is a schematic diagram of a specific hardware structure of a decoder provided in an embodiment of the present disclosure; and

[0054] FIG. 34 is a schematic diagram of an integral structure of a codec system provided in an embodiment of the present disclosure.

DETAILED DESCRIPTION

[0055] For better understanding the characteristics and technical content of the embodiments of the present disclosure in more detail, the implementation of the embodiments of the present disclosure is described in detail in conjunction with the accompanying drawings. The accompanying drawings are for reference and description only, and are not used to define the embodiments of the present disclosure.

[0056] Unless otherwise defined, all technical and scientific terms used herein have the same meanings as are generally understood by those skilled in the art of the present disclosure. The terminology used herein is only for the purpose of describing embodiments of the present disclosure and is not intended to limit the present disclosure.

[0057] In the following description, reference is made to "some embodiments" which describe a subset of all possible embodiments, but it will be appreciated that "some embodiments" may be the same subset or different subsets of all possible embodiments and may be combined with each other without conflict.

[0058] It is also to be noted that the terms "first\ second\ third" referred to In an embodiment of the present disclosure, are used only to distinguish similar objects and do not represent a particular ordering for objects, and that "first\ second\ third" may understandably be interchangeable in a particular order or order where permitted, so that the embodiments of the present disclosure described herein can be implemented in an order other than that illustrated or described herein.

[0059] In embodiments of the present disclosure, bitstreams of different data formats may be allowed to be decoded and synthesized in the same video scene. The data formats may include at least an image format, a Point Cloud format, and a Mesh format. In this way, real-time immersive video interaction services can be provided for multiple data formats (e.g., meshes, point clouds, images, etc.) with different sources.

[0060] In an embodiment of the present disclosure, a data format-based method may allow independent processing at the bitstream level of the data format. That is, similar to tiles or slices in video coding, different data formats in this scene can be encoded in an independent manner, so that independent encoding and decoding can be performed based on the data format.

[0061] Generally, three-dimensional animation content is represented based on key frames, that is, each frame is a static mesh. Static meshes at different times have the same topological structure and different geometry structures. However, the amount of data in key frame representation-based three-dimensional dynamic mesh is huge, so how to store, transmit and render effectively has become a problem faced by the development of three-dimensional dynamic mesh. In addition, different user terminals (e.g., computers, notebooks, portable devices, mobile phones) need to support the spatial scalability of the mesh. Different network bandwidths (e.g., broadband, narrowband, wireless) need to support quality scalability of the mesh. Therefore, three-dimensional dynamic mesh compression is a very critical problem. Here, "a frame" can be understood as an image. For example, a key frame may be understood as a key image in a three-dimensional animation.

[0062] The key terms and related techniques involved in the embodiments of the present disclosure are described before further detailed description of the embodiments of the present disclosure.

[0063] (1) Key terms.

[0064] The terms referred to in an embodiment of the present disclosure apply to the following explanations:

[0065] Mesh – is a collection of vertices, edges, and faces that defines the shape/topology of a polyhedral object. The faces usually consist of triangles (triangle mesh).

[0066] Base mesh – is a mesh with fewer vertexes but preserves similarity to the original surface.

[0067] Dynamic mesh – is a mesh with at least one of the five components (Connectivity, Geometry, Mapping, Vertex Attribute, and Attribute Map) varying in time.

[0068] Animated mesh – is a dynamic mesh with constant connectivity.

[0069] Parametrized mesh – is a mesh with the topology defined as the Mapping component.

[0070] Connectivity – a set of vertex indices describing how to connect the mesh vertices to create a 3D surface. (Geometry and all the attributes share the same unique connectivity information).

[0071] Geometry – a set of vertex 3D (x,y,z) coordinates describing positions associated with the mesh vertices. The (x,y,z) coordinates representing the positions should have finite precision and dynamic range.

[0072] Mapping – a description of how to map the mesh surface to 2D regions of the plane. Such mapping is described by a set of UV parametric/texture [mapping] coordinates associated with the mesh vertices together with the connectivity information.

[0073] Vertex attribute – a scalar of vector attribute values associated with the mesh vertices.

[0074] Attribute Map – attributes associated with the mesh surface and stored as 2D images/videos. The mapping between the videos (i.e., parametric space) and the surface is defined by the mapping information.

[0075] Vertex – a position (usually in 3D space) along with other information such as color, normal vector, and texture coordinates.

[0076] Edge – a connection between two vertices.

[0077] Face – a closed set of edges in which a triangle face has three edges defined by three vertices. Orientation of the face is determined using a "right-hand" coordinate system.

[0078] Surface – a collection of faces that separates the three-dimensional object from the environment.

[0079] bpp – bits per point, an amount of information in terms of bits used to describe one point in the mesh.

[0080] Displacements – the difference between the original mesh geometry and the mesh geometry reconstructed due to the base mesh subdivision process.

[0081] LoD (Level of details) – scalable representation of mesh reconstruction, each level of detail contains enough information to reconstruct mesh to an indicated precision or spatial resolution. Each following LOD is a refinement on top of the plurality of previously reconstructed mesh.

[0082] (2) related technologies.

[0083] Current algorithms apply a two-stage coding process to encode geometry information. First, the geometry is decimated to create a base mesh encoded using generic geometry coding methods, e.g., "edgebreaker." Then the base mesh is hierarchically subdivided, and the difference between the subdivided point and the approximation of the original mesh is stored as the geometry displacement components. The displacement components are packed into a 2-dimensional image and encoded with lossless video coding methods such as High Efficiency Video Coding (HEVC). A high-level diagram of the two-stage geometry coding process is described in FIG. 1.

[0084] In FIG. 1, a static or dynamic mesh is input to a preprocessing module for decimating geometry information to generate a base mesh and displacement components. Then, the decimated base mesh is encoded by a general-purpose mesh encoder (such as an "edgebreaker"), and the displacement components are packaged into a 2-dimensional image, and then the displacement information is encoded by a video encoder such as HEVC, and the resulting encoded bits are written into a bitstream.

[0085] The process of generating displacements for a face in a base mesh with one refinement step is described in FIG. 2. PB1, PB2, and PB3 denote the base mesh points, PS1, PS2, and PS3 represent subdivided points, and PSD1, PSD2, and PSD3 represent displaced subdivided points. Here, the subdivided point PS1 is calculated as a mid-point between the PB1 and PB2 points. The process can be recursively repeated.

[0086] In FIG. 3, each vector of PS1 and PSD1 is described by three components in normal, tangent and bitangent directions. The three components are further processed with wavelet transform and the corresponding transform coefficients can be converted to integer representation, subsequently integerized wawlelet coefficients can be mapped to colour planes (e.g., Y, U, and V components in the YUV 444 color-space), or sequentially mapped to a single colour plane (e.g. Y plane component in the YUV 420, or YUV 400 color-space), or packed using interleaving method between color planes (e.g., Y, U, and V components in the YUV 420 color space).

[0087] The subdivision process is recursively repeated until a desired point density is achieved. An example of the recursive subdivision in 2-dimensional space using displacement in a direction of a normal to surface is described in FIG. 4. As shown in FIG. 4, in the iterative subdivision process, (a), (c) and (e) are third-level subdivision processes of convex continuous surfaces, and (b), (d) and (f) are third-level subdivision processes of oscillatory surfaces.

[0088] In an example, there are three LOD subdivisions, and the subdivision process includes the following steps.

[0089] In step 1, an edge is defined using two neighboring points PB0 and PB1 in a reconstructed base mesh.

[0090] In step 2, normal to the edge is calculated using a face that contains point PB0 and PB1.

[0091] In step 3, a reconstructed base mesh is subdivided at point PS1_1

[0092] In step 4, displacement d1_1 is applied to point PS1_1 along the normal defined in step 2.

[0093] In step 5, two edges: PB0 PS1_1 and PS1_1 PB1 are created.((a) and (b) in FIG.4)

[0094] In step 6, steps 3 - 5 are applied to each new edge from step 5 until desired LoD is generated ((c), (e), (b) and (d) in FIG. 4)

[0095] It is to be noted that the normal is always calculated with reference to the reconstructed base mesh. In addition, the displacements are calculated with reference to the subdivision edges generated in step 5, rather than the reconstructed base edges obtained in step 1.

[0096] Further, a flowchart of a subdivision process is shown in FIG. 5. In FIG. 5, in step S501, an original mesh is decimated to obtain a base mesh. In step S502, the base mesh is quantized. In step S503, the quantized base mesh is encoded. In step S504, the base network is decoded from a bitstream to obtain a reconstructed base mesh. In step S505, n = 0 is initialized, and the reconstructed base mesh is subdivided to obtain a subdivided mesh. In step S506, it is determined whether n is less than L-1. If the determination result is yes, that is, n < L-1, then n = n+1 (S507), and steps S505 to S506 are performed. If the result of the determination in step S506 is NO, that is, n < L−1 is not established, the subdivision is completed, and then steps S508 and S509 are performed. That is to say, after the subdivision is completed, the displacement coefficients are obtained by calculating the subdivided mesh and the original mesh, and the displacement coefficients are encoded into the bitstream.

[0097] Here, n represents the number of iteration subdivisions, and n is an integer indexed from 0, that is, n is an integer greater than or equal to 0. L denotes the number of LODs, and L is an integer indexed from 1.

[0098] Exemplary, FIG. 6 provides a mesh subdivision result of a three-dimensional content with 2 LODs and 1-dimensional displacements. Here, the black solid line (composed of vertices PB_1, PB_2 and PB_3) represents the base mesh, the black dashed line represents the subdivided mesh, the first thick solid line is the LOD1 applied to the displacements, and the second thick solid line is the LOD2 applied to the displacements.

[0099] Furthermore, FIG. 7 provides a schematic diagram of an encoding process of a parameterized mesh. The encoding process is as follows.

[0100] The base mesh frame is quantized and encoded using a static mesh encoder. This process is independent of the type of encoding scheme used to compress the base mesh.

[0101] The displacements are generated using hierarchical subdivision process and represent the difference between the original mesh topology and previously reconstructed subdivided LOD. The first iteration of the displacements is using base mesh as input.

[0102] The displacements are processed by a hierarchical wavelet transform (or other transform) that recursively applies LODs to the reconstructed base mesh.

[0103] The wavelet coefficients are then quantized, packed into a 2-dimensional image/video, and can be compressed by using a traditional image/video encoder.

[0104] The reconstructed version of the wavelet coefficients is obtained by applying image unpacking and inverse quantization to the reconstructed wavelet coefficient image/video generated during the image/video decoding process.

[0105] Reconstructed displacements are then computed by applying the inverse wavelet transform to the reconstructed wavelet coefficients.

[0106] Wavelet coefficients are calculated in floating-point format and may be positive and negative. In some systems, to compose a 2-dimensional image, the coefficients are first converted to positive and mapped to a given bit-depth.

[0107] c'(i) = 2^[bit_depth-1] + [c(i)* 2^bit_depth] / [c_max - c_min],

where c'(i) is integerized displacement coefficient value, c(i) is a current displacement coefficient, c_max is a maximum displacement coefficient value, c_min is a minimum displacement coefficient value, bit-depth is a value that defines a number of fixed levels for image coding.

[0108] FIG. 8 illustrates an example of geometry information in a mesh frame, specifically, an example of a data structure of a mesh, each vertex of which has attributes.

[0109] FIG. 9 illustrates an example of a surface of a mesh consisting of four vertices and three faces, and FIG. 10 illustrates an example of a data structure of a mesh consisting of four vertices and three faces. FIG. 9 shows an example of a surface, represented by a mesh with color-per-vertex characteristics (FIG. 8) that consists of four vertices and three faces, is demonstrated in FIG. 9. Each vertex in space is described by its X, Y, Z position coordinates, and three color attributes R, G, B. As shown below, each face is defined by three vertex indices that form a triangle.

```
# ---------------------------------
# Part 1 :
#  geometry information
#   X   Y   Z  a_1  a_2  a_3
#  vertex  0 (v_idx_0)
v   0.0 0.0 0.0 127 127 127
#  vertex 1 (v_idx_1)
v   1.0 0.0 0.0 127 127 127
#  vertex 2 (v_idx_2)
v   0.0 1.0 0.0 127 127 127
```

```
#   vertex 3 (v_idx_3)
v    0.0 0.0 1.0 127 127 127
# ---------------------------------
# Part 2 :
#   connectivity information
# v_idx, v_idx, v_idx
# face 0 (f_idx_0)
f    0 1 2
# face 1 (f_idx_1)
f    0 3 1
# face 2 (f_idx_2)
f    0 2 3
# ---------------------------------
```

[0110] An example of a data structure with a parameterized mesh with an attribute texture map is shown in FIG. 11.

[0111] FIG. 12 shows an example of a surface, represented by a mesh with attribute mapping characteristics (FIG. 11) that consists of four vertices and three faces. Each vertex in space is described by its X, Y, Z position coordinates. (U, V) denotes attribute coordinates in the 2-dimensional texture vertex map. Each face is defined by three pairs of vertex indices and texture vertex coordinates that form a triangle in 3-dimensional space and a triangle in the 2-dimensional texture map.

```
# ---------------------------------
# Part 1 :
#   geometry information
#   X     Y     Z
# vertex 0 (v_idx_0)
v   0.0 0.0 0.0
# vertex 1 (v_idx_1)
v   1.0 0.0 0.0
# vertex 2 (v_idx_2)
v   0.0 1.0 0.0
# vertex 3 (v_idx_3)
v   0.0 0.0 1.0
# ---------------------------------
# Part 2 :
#   mapping information
#   U     V
#   texture vertex 0 (vt_0)
vt 0.500000 0.500000
#   texture vertex 1 (vt_1)
vt 0.000000 0.500000
#   texture vertex 2 (vt_2)
vt 0.500000 1.000000
#   texture vertex 3 (vt_3)
vt 1.000000 0.500000
#   texture vertex 4 (vt_4)
vt 0.500000 0.000000
# ---------------------------------
# Part 3 :
#   connectivity information
#   v_idx / vt_idx
# face 0 (f_idx_0)
f    0/0 1/2 2/1
# face 1 (f_idx_1)
f    0/0 3/2 1/3
# face 2 (f_idx_2)
f    0/0 2/3 3/4
```

[0112] In an embodiment of the present disclosure, the orientation of a face is determined using the right-hand coordinate system. A face consists of three vertices that belong to three edges, and the three vertex indices describe each face.

[0113] Manifold mesh is a mesh where one edge belongs to two different faces at most, as shown in FIG. 13A. Non-manifold mesh is a mesh with an edge that belongs to more than two faces, as shown in FIG. 13B.

[0114] Furthermore, to encode the displacements component using existing video encoding standards, the transformed displacement components are mapped from a one-dimensional array to a 2-dimensional image, as shown in FIG. 14.

[0115] Each unit vector component is associated with a different color plane. In an example, the Normal unit vector is mapped to Y-plane; the Tangent unit vector is mapped to U-plane; the BiTangent unit vector is mapped to V-plane. In this case, YUV444 color mapping is used for encoding. As shown in FIGS. 15A and 15B, an example of Video component for displacement coefficients 8x8 packing block is provided. FIG. 15A shows forward packing, and FIG. 15B shows backward packing.

[0116] The nature of the lifting transform used in displacement coefficient coding leads to independent subdivision levels with a separate set of coefficients used for reconstruction.

[0117] In a related technique, as shown in FIG. 5, the displacement coefficients are applied to the previously reconstructed LODs. The displacements coefficients are often redundant at the higher LODs, in some instances, which usually results in a large bit overhead and reduces the efficiency of encoding and decoding.

[0118] In view of the above, an embodiment of the present disclosure provides an encoding method and decoding method, by adding a first syntax element which indicates that the current mesh adopts a nonlinear subdivision mode, and when it is determined that the current mesh adopts a nonlinear subdivision mode, the reconstructed mesh of the current LOD in the current mesh is subdivided to determine a subdivided mesh of the current LOD. The displacement coefficients of first points (points coinciding with or neighboring a base point) of the current LOD is directly set to 0. That is, the displacements neighboring the base point (e.g., PB_1, PB_2, and PB_3) are inferred to be equal to 0. According to the subdivided mesh of the current LOD and the displacement coefficients of the current LOD, a reconstructed mesh of the next LOD in the current mesh is determined. In this way, when the non-linear subdivision method is adopted in the current mesh, the redundancy problem of the displacement coefficients in the higher levels can be further improved, the encoded bits of the displacement coefficients may be reduced, and the encoding and decoding efficiency can be improved.

[0119] That is, in an embodiment of the present disclosure, by adding a first syntax element indicating that the current mesh adopts a non-linear subdivision method, displacement coefficients that are close to a vertex in a base layer may be dropped from the displacement list at the encoder stage, and the displacement coefficients that are close to the vertex in the base layer are inferred to be equal to zero in the decoder stage. Therefore, in the subsequent process of recursively applying the displacement coefficients to the previously reconstructed LOD, the redundancy problem of the displacement coefficients at the higher levels can be improved, the encoded bits of the displacement coefficients can be reduced, and the encoding and decoding efficiency can be improved.

[0120] In order to facilitate understanding of the technical solutions of embodiments of the present disclosure, the technical solutions of the present disclosure are described in detail below with specific embodiments. The above-mentioned related technologies can be arbitrarily combined with the technical solutions of the embodiments of the present disclosure as optional solutions, and all of them belong to the protection scope of the embodiments of the present disclosure. Embodiments of the present disclosure include at least some of the following contents.

[0121] FIG. 16 is a flowchart of a decoding method provided in an embodiment of the present disclosure. As shown in FIG. 16, the method may include the following steps.

[0122] In step 101, the bitstream is decoded and a value of the first syntax element is determined.

[0123] It is to be noted that in an embodiment of the present disclosure, the decoding method may refer to a mesh subdivision method, in particular, a recursive subdivision method for dynamic mesh decoding, which can improve the encoding and decoding efficiency.

[0124] It is also to be noted that, in an embodiment of the present disclosure, Video-based Dynamic Mesh Coding (VDMC) is a standard for compressing three-dimensional meshes, which mainly compresses three-dimensional meshes using an existing video-based Visual Volumetric Video-based Coding (V3C) standard. In an embodiment of the present disclosure, the subdivision method shares functionality across all LODs and is defined by two syntax elements asps_vdmc_ext_subdivision_method and asps_vdmc_ext_subdivision_iteration_count in the Atlas sequence parameter set VDMC extension RBSP syntax structure.

[0125] Here, Table 1 provides a schematic syntax structure of the Atlas sequence parameter set VDMC extension.

Table 1

asps_vdmc_extension( ) {	Descriptor
asps_vdmc_ext_subdivision_method	**u(3)**
if(asps_vdmc_ext_subdivision_method != 0)	
asps_vdmc_ext_subdivision_iteration_count	**u(8)**
asps_vdmc_ext_displacement_coordinate_system	**u(1)**
asps_vdmc_ext_transform_method	**u(3)**
…	
}	

asps_vdmc_extension( ) {	Descriptor
asps_vdmc_ext_subdivision_method	u(3)
if(asps_vdmc_ext_subdivision_method != 0)	
asps_vdmc_ext_subdivision_iteration_count	u(8)
asps_vdmc_ext_displacement_coordinate_system	u(1)
asps_vdmc_ext_transform_method	u(3)
…	
}	

[0126] In Table 1, asps_vdmc_ext_subdivision_method indicates the identifier of the method to subdivide the meshes associated with the current atlas sequence parameter set, asps_vdmc_ext_subdivision_iteration_count indicates the number of subdivision iterations of the mesh, asps_vdmc_ext_disposition_coordinate_system indicates the coordinate system identifier of the mesh, and asps_vdmc_ext_transform_method indicates the wavelet transform identifier of the mesh.

[0127] Here, for asps_vdmc_ext_subdivision_method, Table 2 describes a list of supported subdivision methods corresponding to asps_vdmc_ext_subdivision_method.

Table 2

asps_vdmc_ext_subdivision_method	Name of subdivision method
0	NONE
1	MIDPOINT

[0128] For asps_vdmc_ext_subdivision_iteration_count, the value of asps_vdmc_ext_subdivision_iteration_count is inferred to be equal to 0 when it does not exist.

[0129] For asps_vdmc_ext_disposition_coordination_system, Table 3 describes a list of supported coordinate systems corresponding to asps_vdmc_ext_disposition_coordination_system.

Table 3

Asps_vdmc_ext_disposition_coordinate_system	Name of the coordinate system
0	CANNONICAL (canonical coordinate system)
1	LOCAL (LOCAL Coordinate System)

[0130] For asps_vdmc_ext_transform_method, Table 4 describes a list of correspondences between the supported wavelet transform methods and asps_vdmc_ext_transform_method.

Table 4

Asps_vdmc_ext_transform_method	Name of the transform method
0	NONE
1	LINEAR_LIFTING

[0131] In an embodiment of the present disclosure, the first syntax element herein may be represented by asps_vdmc_ext_subdivision_method for indicating a subdivision method of the mesh, which may be, for example, midpoint subdivision, Loop subdivision, or the like.

[0132] Due to specifics of the subdivision, higher LODs often degenerate to "0" displacement introducing significant redundancy in signaling and coding information.

[0133] In view of the above, for efficient coding of the geometry component of the mesh representation of the volumetric content, redundant displacements are removed in cases such as base mesh edge and inheriting value from previous LOD. An embodiment of the present disclosure provides a new adaptive subdivision method in which edges that are neighboring the base points at higher LODs shall be always equal to 0.

[0134] It will be appreciated that in embodiments of the present disclosure, on the basis of Table 2 above, new values are added for the first syntax element so that the first syntax element can be used to indicate whether the current mesh adopts a non-linear subdivision method. Here, the non-linear subdivision may create same subdivision as that in the related arts. However, the displacements neighboring base point (e.g., PB_1, PB_2, and PB_3) are inferred to be equal to zero. Simply put, for each LOD, the displacements are calculated based on the subdivision vertices in the previously reconstructed LOD, so that the displacements can be recursively applied to the previously reconstructed LOD. Therefore, the adaptive subdivision method here is called "Recursive subdivision method". Taking midpoint subdivision as an example, this recursive subdivision method can be called midpoint recursive subdivision method.

[0135] In a possible implementation, as shown in Table 5, a new asps_vdmc_ext_subdivision_method equal to 2 and 3 are added, The new asps_vdmc_ext_subdivision_method would create same subdivision as that in the related arts. However, the displacements neighboring base point (e.g., PB_1, PB_2, and PB_3) are inferred to be equal to zero, thereby saving the coded bits of the displacements.

Table 5

asps_vdmc_ext_subdivision_method	Name of subdivision method
0	NONE
1	MIDPOINT
2	MIDPOINT RECURSIVE
3	NONLINEAR

[0136] In step 102, when the first syntax element indicates that the current mesh adopts a non-linear subdivision mode, the reconstructed mesh of the current LOD in the current mesh is determined, and the reconstructed mesh of the current LOD is subdivided to determine the subdivided mesh of the current LOD.

[0137] It is to be noted that, in an embodiment of the present disclosure, the first syntax element indicates whether the current mesh adopts a non-linear subdivision mode. Here, when the value of the first syntax element is the first value, it is determined that the first syntax element indicates that the current mesh does not adopt the subdivision mode; when the value of the first syntax element is a second value, it is determined that the first syntax element indicates that the current mesh adopts a midpoint subdivision mode; when the value of the first syntax element is a third value, it is determined that the first syntax element indicates that the current mesh adopts a recursive subdivision mode; and when the value of the first syntax element is a fourth value, it is determined that the first syntax element indicates that the current mesh adopts a non-linear subdivision mode.

[0138] Here, the first value, the second value, the third value, and the fourth value are different from each other. For example, the first value may be set to 0, the second value may be set to 1, the third value may be set to 2, and the fourth value may be set to 3. That is, according to the different values of the first syntax element, it is possible to determine whether the current mesh adopts s a non-linear subdivision method.

[0139] In an embodiment, if the value of the first syntax element is 0, it can be determined that the current mesh does not adopt any subdivision, such as midpoint subdivision, recursive subdivision, nonlinear subdivision, and the like. If the value of the first syntax element is 1, it can be determined that the current mesh adopts midpoint subdivision. If the value of the first syntax element is 2, it can be determined that the current mesh is subdivided recursively. If the value of the first syntax element is 3, it can be determined that the current mesh adopts a non-linear subdivision.

[0140] It is also to be noted that in an embodiment of the present disclosure, when the non-linear subdivision method is adopted for the current mesh, the reconstructed mesh of the current mesh may be obtained by recursive reconstruction of at least one LOD. Specifically, after obtaining the reconstructed mesh of the current LOD in the current mesh, the reconstructed mesh of the current LOD may be subdivided to determine the subdivided mesh of the current LOD. Then, a reconstructed mesh of the next LOD of the current LOD may be recursively obtained according to the subdivided mesh, and preset displacement coefficients or displacement coefficients in the bitstream.

[0141] In some embodiments, a reconstructed mesh of the first LOD of the current mesh is firstly determined. The method may include: decoding the bitstream to determine a reconstruction base mesh; subdividing the reconstructed base mesh to determine an initial subdivided mesh; decoding the bitstream to determine displacement coefficients of the initial subdivided mesh; determining a reconstructed mesh of the first LOD in the current mesh according to the initial subdivided mesh and the displacement coefficients of the initial subdivided mesh,.

[0142] In an embodiment of the present disclosure, the base mesh may also be referred to as a "decimated mesh". In some embodiments, a reconstructed base mesh is determined by decoding the base mesh bitstream. For example, the base mesh bitstream may be decoded by a mesh decoder (such as EdgeBreaker) to obtain a reconstructed base mesh.

[0143] In some embodiments, after determining the reconstructed mesh of the first LOD in the current mesh, the reconstructed mesh of the first LOD is subdivided to determine a subdivided mesh of the second LOD, the bitstream is decoded to determine displacement coefficients of the subdivided mesh of the seond LOD, a reconstructed mesh of a next LOD of the current mesh is determined according to the subdivided mesh of the second LOD and the displacement coefficients of the subdivided mesh of the second LOD, andsubdivision operation is continued, until the reconstructed mesh of the L-th LOD in the current mesh is determined. The value of L is correlated with the number of subdivision iterations of the current mesh.

[0144] In an embodiment of the present disclosure, for the first LOD, the displacement coefficient refers to the difference between the vertex coordinate information of the original mesh and the vertex coordinate information of the initial subdivided mesh. In this way, after the displacement coefficients of the initial subdivided mesh are decoded, the corresponding displacement operation is performed on the vertex coordinate information of the initial subdivided mesh according to the displacement coefficient, and the reconstructed mesh of the first LOD, i.e., the reconstructed mesh of LOD1, may be obtained. Then, the reconstructed mesh is subdivided based on LOD1 to obtain a subdivided mesh on LOD1, and a reconstructed mesh of LOD2 may be determined according to the subdivided mesh on LOD1and corresponding displacement coefficients, and so on until the reconstruction is completed.

[0145] In step 103, when the current LOD is the i-th LOD, the displacement coefficients of the first points of the current LOD are determined to be 0. Here, i is an integer greater than 2. The first points include vertices of the reconstructed base mesh corresponding to the current mesh.

[0146] It is to be noted that, in embodiments of the present disclosure, the displacement coefficients may include displacement components in one or more directions. As shown in FIG. 3, the displacement coefficients include displacement components in three directions, namely, the normal direction, the tangent direction, and the bitangent direction. Here, the displacement coefficients of the first LOD are calculated relative to the subdivision vertices of the base mesh, and the displacement coefficients of the subsequent LODs are calculated relative to the subdivision vertices of the reconstructed LOD of a previous LOD, so that the recursive subdivision of the displacement coefficients can be realized.

[0147] It is to be noted that in an embodiment of the present disclosure, if the current LOD is the i-th LOD and i is an integer greater than 2, that is, the current LOD satisfies that LoD is greater than 2, then the displacement coefficients of the first points of the current LOD may be determined to be 0.

[0148] It is to be noted that, in embodiments of the present disclosure, the first points of the current LOD include vertices of the reconstructed base mesh corresponding to the current mesh, that is, the first points may be understood as a points coinciding with or neighboring a base point (e.g., PB_1, PB_2, PB_3).

[0149] That is, in an embodiment of the present disclosure, if the first syntax element indicates that the current mesh adopts a non-linear subdivision mode, and the current LOD is greater than 2, then the displacement coefficients of the first points of the current LOD may be directly set to 0, and subsequent mesh reconstruction may be carried out using the displacement coefficients.

[0150] In step 104, a reconstructed mesh of the next LOD in the current mesh is determined based on the subdivided mesh of the current LOD and the displacement coefficients of the first points of the current LOD.

[0151] It is to be noted that in an embodiment of the present disclosure, according to the subdivided mesh of the current LOD and the displacement coefficients of the first points of the current LOD, the reconstructed mesh of the next LOD in the current mesh is determined. Specifically, according to the displacement coefficients of the first points, displacements are calculated based on the vertex coordinate information of the subdivided mesh of the current LOD, and then the reconstructed mesh of the next LOD in the current mesh is obtained.

[0152] That is, in an embodiment of the present disclosure, the displacement coefficients are recursively applied to the previously reconstructed LOD, specifically, the decoded displacement coefficient is added to each vertex of the subdivided mesh of the current LOD in order, so that the reconstructed mesh of the next LOD may be obtained.

[0153] It can be understood that in an embodiment of the present disclosure, when the first syntax element indicates that the current mesh adopts a nonlinear subdivision mode, if the current LOD is greater than 2, then the displacement coefficients of the first points of the current LOD is set to 0, that is, the displacements of the points (first points) overlapping or neighboring the base point are set to 0. At this time, in the process of obtaining a reconstructed mesh, the displacement calculation for the first point is actually carried out on the subdivided mesh of the current LOD and 0.

[0154] In some embodiments, the method may further include: after determining the reconstructed mesh of the next LOD in the current mesh, taking the reconstructed mesh of the next LOD as the reconstructed mesh of the current LOD, returning to performing the step of subdividing the reconstructed mesh of the current LOD, and determining the subdivided mesh of the current LOD until the reconstructed mesh of the L-th LOD in the current mesh is determined. The value of L is correlated with the number of subdivision iterations of the current mesh.

[0155] It is also to be noted that in an embodiment of the present disclosure, the number of subdivision iterations of the current mesh may be indicated by a second syntax element in the bitstream. In an embodiment, the method may include: decoding a bitstream to determine a value of a second syntax element; determining the number of subdivision iterations of the current mesh according to the value of the second syntax element.

[0156] In an embodiment of the present disclosure, the second syntax element may be represented by asps_vmc_ext_subdivision_iteration_count. That is, the number of subdivision iterations for the current mesh may be a value indicated by asps_vmc_ext_subdivision_iteration_count in the bitstream.

[0157] In addition, L represents the number of LODs corresponding to the current mesh, and the value of L may be determined by the number of subdivision iterations of the current mesh, that is, the value of L is equal to the value indicated by asps_vmc_ext_subdivision_iteration_count.

[0158] Furthermore, FIG. 17 is a second flowchart of a decoding method provided in an embodiment of the present disclosure. As shown in FIG. 17, after step 102, the method may include the following steps.

[0159] In step 105,the bitstream is decoded to determine the displacement coefficients of the second points of the current LOD if the current LOD is the i-th LOD. Here, the second points do not include the vertices of the reconstructed base mesh corresponding to the current mesh. In other words, the second points are points of the reconstructed base mesh corresponding to the current mesh except the first points.

[0160] It is to be noted that in an embodiment of the present disclosure, if the current LOD is the i-th LOD and i is an integer greater than 2, that is, the current LOD satisfies that LoD is greater than 2, then the displacement coefficients of the first points of the current LOD may be determined to be 0, and the displacement coefficients of the second points may be obtained by decoding the bitstream. Here, the bitstream may be a displacement bitstream. There are also a variety of specific decoding methods for the displacement bitstream, such as video decoding, entropy decoding and so on. That is, in an embodiment of the present disclosure, the displacement information may be obtained by decoding using a video decoder, or the displacement information may be obtained by decoding with an entropy decoder, without any limitation herein.

[0161] It is to be noted that, in an embodiment of the present disclosure, the second points of the current LOD do not include vertices of the reconstructed base mesh corresponding to the current mesh, i.e., the second points may be understood as point that are not close to the base point (e.g., PB_1, PB_2, PB_3).

[0162] That is, in an embodiment of the present disclosure, if the first syntax element indicates that the current mesh adopts a non-linear subdivision mode, and the current LOD is greater than 2, on the one hand, the displacement coefficients of the first points of the current LOD may be set to 0, and at the same time, the displacement coefficients of the second points of the current LOD may be determined by decoding the bitstream.

[0163] In step 106, a reconstructed mesh of the next LOD in the current mesh is determined based on the subdivided mesh of the current LOD and the displacement coefficients of the second points of the current LOD.

[0164] It is to be noted that in an embodiment of the present disclosure, according to the subdivided mesh of the current LOD and the displacement coefficients of the second points of the current LOD, the reconstructed mesh of the next LOD in the current mesh is determined, specifically, according to the displacement coefficients of the second points, the corresponding displacement operation is performed on the vertex coordinate information of the subdivided mesh of the current LOD, and the reconstructed mesh of the next LOD in the current mesh is obtained.

[0165] That is, in an embodiment of the present disclosure, the displacement coefficients is recursively applied to the previously reconstructed LOD, specifically, the decoded displacement coefficients are added to respective vertices of the subdivided mesh of the current LOD in order, so that the reconstructed mesh of the next LOD can be obtained.

[0166] Furthermore, in an embodiment of the present disclosure, FIG. 18 is a third flowchart of a decoding method provided in an embodiment of the present disclosure. As shown in FIG. 18, after step 102, the method may include the following steps.

[0167] In step 107, when the current LOD is a second LOD, the bitstream is decoded to determine the displacement coefficient of the current LOD.

[0168] It is to be noted that in an embodiment of the present disclosure, when the current LOD is a second LOD, that is, the current LOD is LoD 2, the displacement coefficients of the current LOD may be obtained by decoding the bitstream. Here, the bitstream may be a displacement bitstream. There are also a variety of specific decoding methods for the displacement bitstream, such as video decoding, entropy decoding and so on. That is, in an embodiment of the present disclosure, the displacement information may be obtained by decoding using a video decoder, or the displacement information may be obtained by decoding using an entropy decoder, without any limitation herein.

[0169] In step 108, a reconstructed mesh of the next LOD in the current mesh is determined based on the subdivided mesh of the current LOD and the displacement coefficients of the current LOD.

[0170] It is to be noted that in an embodiment of the present disclosure, according to the subdivided mesh of the current LOD and the displacement coefficients of the current LOD, the reconstructed mesh of the next LOD in the current mesh is determined, specifically, according to the displacement coefficients, the corresponding displacement operation is performed on the vertex coordinate information of the subdivided mesh of the current LOD, and the reconstructed mesh of the next LOD in the current mesh is obtained.

[0171] That is, in an embodiment of the present disclosure, the displacement coefficients are recursively applied to the previously reconstructed LOD, specifically, the decoded displacement coefficient is added to each vertex of the subdivided mesh of the current LOD in order, so that the reconstructed mesh of the next LOD can be obtained.

[0172] In some embodiments, the method may further include: after determining the reconstructed mesh of the next LOD in the current mesh, taking the reconstructed mesh of the next LOD as the reconstructed mesh of the current LOD, returning to performing the step of subdividing the reconstructed mesh of the current LOD, and determining the subdivided mesh of the current LOD until the reconstructed mesh of the L-th LOD in the current mesh is determined. The value of L is correlated with the number of subdivision iterations of the current mesh.

[0173] It is also to be noted that in an embodiment of the present disclosure, the number of subdivision iterations of the current mesh may be indicated by a second syntax element in the bitstream. In an embodiment, the method may include: decoding a bitstream to determine a value of a second syntax element; and determining the number of subdivision iterations of the current mesh according to the value of the second syntax element,.

[0174] In an embodiment of the present disclosure, the second syntax element may be represented by asps_vmc_ext_subdivision_iteration_count. That is, the number of subdivision iterations for the current mesh may be a value indicated by asps_vmc_ext_subdivision_iteration_count in the bitstream.

[0175] In addition, L represents the number of LODs corresponding to the current mesh, and the value of L may be determined by the number of subdivision iterations of the current mesh, that is, the value of L is equal to the value indicated by asps_vmc_ext_subdivision_iteration_count.

[0176] Furthermore, in an embodiment of the present disclosure, FIG. 19 is a fourth flowchart of a decoding method provided in an embodiment of the present disclosure. As shown in FIG. 19, after step 101, the method may include the following steps.

[0177] In step 109, when the first syntax element indicates that the current mesh adopts a recursive subdivision mode, a reconstructed mesh of the current LOD in the current mesh is determined, and the reconstructed mesh of the current LOD is subdivided to determine a subdivided mesh of the current LOD.

[0178] It is to be noted that, in an embodiment of the present disclosure, the first syntax element may also indicates whether the current mesh adopts recursive subdivision. Herein, when the value of the first syntax element is the first value, it is determined that the first syntax element indicates that the current mesh does not adopt the subdivision mode; when the value of the first syntax element is a second value, it is determined that the first syntax element indicates that the current mesh adopts a midpoint subdivision mode; when the value of the first syntax element is a third value, it is determined that the first syntax element indicates that the current mesh adopts a recursive subdivision mode; and when the value of the first syntax element is a fourth value, it is determined that the first syntax element indicates that the current mesh adopts a non-linear subdivision mode.

[0179] Here, the first value, the second value, the third value, and the fourth value are different from each other. For example, the first value may be set to 0, the second value may be set to 1, the third value may be set to 2, and the fourth value may be set to 3. That is, according to the different values of the first syntax element, it is possible to determine whether the current mesh adopts a recursive subdivision method.

[0180] In an embodiment, if the value of the first syntax element is 0, it may be determined that the current mesh does not adopt any subdivision, such as midpoint subdivision, recursive subdivision, nonlinear subdivision, and the like; if the value of the first syntax element is 1, it may be determined that the current mesh adopts midpoint subdivision; if the value of the first syntax element is 2, it may be determined that the current mesh is subdivided recursively; if the value of the first syntax element is 3, it may be determined that the current mesh adopts a non-linear subdivision.

[0181] It is also to be noted that, in an embodiment of the present disclosure, when the current mesh adopts the recursive subdivision method, the reconstructed mesh of the current mesh may be obtained by recursive reconstruction of at least one LOD. Specifically, after obtaining the reconstructed mesh of the current LOD in the current mesh, the reconstructed mesh of the current LOD may be subdivided to determine the subdivided mesh of the current LOD. Then, the reconstructed mesh of the next LOD of the current LOD may be recursively obtained according to the subdivided mesh and the displacement coefficients in the bitstream,.

[0182] In some embodiments, a reconstructed mesh of the first LOD of the current mesh is firstly determined. The method may include: decoding the bitstream to determine a reconstructed base mesh; subdividing the reconstructed base mesh to determine an initial subdivided mesh; decoding the bitstream to determine the displacement coefficients of the initial subdivided mesh; and determining a reconstructed mesh of the first LOD in the current mesh according to the initial subdivided mesh and the displacement coefficients of the initial subdivided mesh.

[0183] In an embodiment of the present disclosure, the base mesh may also be referred to as a "decimated mesh". In some embodiments, a reconstructed base mesh is determined by decoding the base mesh bitstream. For example, the base mesh bitstream may be decoded by a mesh decoder (such as EdgeBreaker) to obtain a reconstructed base mesh.

[0184] In an embodiment of the present disclosure, for the first LOD, the displacement coefficient refers to the difference between the vertex coordinate information of the original mesh and the vertex coordinate information of the initial subdivided mesh. In this way, after the displacement coefficients of the initial subdivided mesh are decoded, the corresponding displacement operation is performed on the vertex coordinate information of the initial subdivided mesh according to the displacement coefficient, and the reconstructed mesh of the first LOD, that is, the reconstructed mesh of LOD1, may be obtained. Then, the reconstructed mesh is subdivided based on LOD1 to obtain a subdivided mesh on LOD1, and then a reconstructed mesh of LOD2 is determined according to the reconstructed mesh of LOD1 and the displacement coefficients, and so on, until the reconstruction is completed.

[0185] In step 110, the bitstream is decoded to determine the displacement coefficient of the current LOD.

[0186] It is to be noted that, in an embodiment of the present disclosure, the displacement coefficients may include displacement components in one or more directions. As shown in FIG. 3, the displacement coefficients include displacement components in three directions, namely, the normal direction, the tangent direction, and the bitangent direction. Here, the displacement coefficients of the first LOD are calculated relative to the subdivision vertices of the base mesh, and the displacement coefficients of the subsequent LODs are calculated by reconstructing the subdivision vertices of LOD of relative to the previous LOD, so that the recursive subdivision of the displacement coefficients can be realized.

[0187] It is also to be noted that in an embodiment of the present disclosure, the displacement coefficients of the current LOD are obtained by decoding the bitstream. Here, the bitstream may be a displacement bitstream. There are also a variety of specific decoding methods for the displacement bitstream, such as video decoding, entropy decoding and so on. That is, in an embodiment of the present disclosure, the displacement information may be obtained by decoding using a video decoder, or the displacement information may be obtained by decoding using an entropy decoder, without any limitation herein.

[0188] In some embodiments, the method of determining the displacement coefficients of the current LOD involved in any one of steps 105, 107, and 110 may specifically include decoding the bitstream to determine the decoded displacement coefficients of the current LOD. The decoded displacement coefficients of the current LOD are inverse quantized according to the quantization parameters of the current LOD, to determine the inverse quantized displacement coefficients of the current LOD. Inverse wavelet transform is performed on the inverse quantized displacement coefficients of the current LOD to determine the displacement coefficients of the current LOD.

[0189] It is to be noted that in an embodiment of the present disclosure, after the displacement coefficients of the current LOD are decoded, the decoded displacement coefficients of the current LOD may be preprocessed to determine the displacement coefficients of the current LOD. Here, the preprocessing may include inverse quantization, inverse wavelet transform and other processing.

[0190] In an embodiment, the decoded displacement coefficients of the current LOD are preprocessed to determine the displacement coefficients of the current LOD, specifically, quantization parameters of the current LOD is determined; the decoded displacement coefficients of the current LOD are inverse quantized according to the quantization parameters of the current LOD to determine the inverse quantized displacement coefficients of the current LOD; inverse wavelet transform is performed on the inverse quantized displacement coefficients of the current LOD to determine the displacement coefficients of the current LOD.

[0191] It is to be noted that in an embodiment of the present disclosure, inverse quantization is an inverse process of quantization, and is used for converting quantized fixed points into floating points; inverse wavelet transform is the inverse process of wavelet transform, which is used to restore the signal in the wavelet domain to the original time domain, so that the displacement coefficients of the current LOD can be obtained.

[0192] It is also to be noted that, in an embodiment of the present disclosure, the Quantizer Parameter (QP) reflects the spatial detail compression situation. Here, the smaller the value, the finer the quantization, the higher the image quality, and the longer the bitstream. If the QP is small, most of the details will be retained; QP increases, some details are lost, bit rate is reduced, but image distortion is enhanced and quality is degenerated. Specifically, QP is the serial number of the quantization step Qstep, and when the value of QP is 0, it means that the quantization is the finest. on the contrary, when the value of QP is 51, it means that the quantization is rougher.

[0193] In a possible implementation, for the current LOD quantization parameters the method may include decoding the bitstream, determining the quantization parameters of the current LOD.

[0194] In another possible implementation, for the quantization parameters of the current LOD, the method may include: determining quantization parameters of a previous LOD of the current LOD; decoding the bitstream to determine a quantization parameter increment of the current LOD. The quantization parameters of the current LOD are determined according to the quantization parameters of the previous LOD and the quantization parameter increment.

[0195] That is to say, the encoder side may directly write the quantization parameters into the bitstream, so that the decoder side may obtain the corresponding quantization parameters through decoding; or the encoder side may write the quantization parameter increment into the bitstream, and then the decoder side may obtain the corresponding quantization parameters according to the quantization parameter increment obtained by decoding and the quantization parameter of the previous LOD.

[0196] For example, assuming that the quantization parameters of the current LOD may be represented by QP(i), the quantization parameters of a previous LOD may be represented by QP (i-1), and the quantization parameter increment may be represented by $\triangle$QP, then QP (i) = QP (i-1) + $\triangle$QP. For the quantization parameter of the first LOD, the corresponding quantization parameter QP (1) may be directly written into the bitstream.

[0197] It is to be noted that in an embodiment of the present disclosure, a reference quantization parameters may also be set at the encoder side and the decoder side, and then the quantization parameter increment between the quantization parameter of each LOD and the reference quantization parameter is written into the bitstream. In this way, after the quantization parameter increment of the current LOD is determined by the decoding the bitstream, the decoder side may determine the quantization parameter of the current LOD according to the quantization parameter increment of the current LOD and the reference quantization parameter, so that the signaling overhead of decoding the quantization parameter can also be saved.

[0198] In some embodiments, decoding the bitstream to determine decoded displacement coefficients for the current LOD may include: decoding the bitstream to determine a two-dimensional image; extracting displacement coefficients from the two-dimensional image according to the preset packing mode to obtain the decoded displacement coefficients of the current LOD.

[0199] In an embodiment of the present disclosure, the decoded displacement coefficients of the current LOD may be determined by decoding the displacement bitstream. Furthermore, the preset packing mode includes a forward packing mode or a inverse packing mode. For determining the preset packing mode, the decoder side and the encoder side may set the same packing mode, or the packing mode may be indicated according to a third syntax element in the bitstream.

[0200] In an embodiment, the method may include: decoding a bitstream to determine a value of a third syntax element; and determining the preset packing mode according to the value of the third syntax element.

[0201] In an embodiment of the present disclosure, the third syntax element may be represented by dmsps_packing_order. That is, the preset packing mode may be the packing mode indicated by dmsps_packing_order in the bitstream.

[0202] Thus, in an embodiment of the present disclosure, the displacement bitstream may be decoded by a displacement decoder. If the encoder side compresses the displacements by video encoding, the decoder side decodes the displacements using corresponding video decoder, and restores it from the two-dimensional image in a corresponding order according to the preset packing mode. Then, inverse quantization is performed on the displacements, inverse wavelet transform and other operations are performed to restore the same displacement coefficients as the encoder side. Otherwise, if the encoder side uses entropy coding for the displacement coefficients, the decoder may directly decode the displacement coefficients using entropy decoding, and then perform subsequent operations such as inverse quantization and inverse wavelet transform to obtain the displacement coefficients of the current LOD.

[0203] In step 1011, a reconstructed mesh of the next LOD in the current mesh is determined according to the subdivided mesh of the current LOD and the displacement coefficients of the current LOD.

[0204] It is to be noted that in an embodiment of the present disclosure, according to the subdivided mesh of the current LOD and the displacement coefficients of the current LOD, the reconstructed mesh of the next LOD in the current mesh is determined, speciffically, a reconstructed mesh of the next LOD in the current mesh is obtained by performing a corresponding displacement operation on the vertex coordinate information of the subdivided mesh of the current LOD according to the displacement coefficients.

[0205] That is, in an embodiment of the present disclosure, the displacement coefficients are recursively applied to the previously reconstructed LOD. Specifically, the decoded displacement coefficients are added to respective vertices of the subdivided mesh of the current LOD in order, so that the reconstructed mesh of the next LOD can be obtained.

[0206] In some embodiments, the method may further include: after determining the reconstructed mesh of the next LOD in the current mesh, taking the reconstructed mesh of the next LOD as the reconstructed mesh of the current LOD, returning to performing the step of subdividing the reconstructed mesh of the current LOD, and determining the subdivided mesh of the current LOD until the reconstructed mesh of the L-th LOD in the current mesh is determined. The value of L is correlated with the number of subdivision iterations of the current mesh.

[0207] It is also to be noted that in an embodiment of the present disclosure, the number of subdivision iterations of the current mesh may be indicated by a second syntax element in the bitstream. In an embodiment, the method may include decoding a bitstream to determine a value of a second syntax element. According to the value of the second syntax element, the number of subdivision iterations of the current mesh is determined.

[0208] In an embodiment of the present disclosure, the second syntax element may be represented by asps_vmc_ext_subdivision_iteration_count. That is, the number of subdivision iterations for the current mesh may be a value indicated by asps_vmc_ext_subdivision_iteration_count in the bitstream.

[0209] In addition, L represents the number of LODs corresponding to the current mesh, and the value of L may be determined by the number of subdivision iterations of the current mesh, that is, the value of L is equal to the value indicated by asps_vmc_ext_subdivision_iteration_count.

[0210] Thus, in an embodiment of the present disclosure, in the case where the first syntax element indicates that the current mesh adopts a recursive subdivision mode, as shown in FIG. 20, the base mesh is subdivided first, and an initial subdivided mesh can be obtained. After the displacement coefficients of the initial subdivided mesh are decoded, a corresponding displacement operation is carried out on the vertex coordinate information of the initial subdivided mesh according to the displacement coefficients, and the reconstructed mesh of the first LOD, that is, the reconstructed mesh of LOD1, may be obtained. Then, the reconstructed mesh is subdivided based on LOD1 to obtain a subdivided mesh on LOD1. Then, after decoding the displacement coefficients of LOD1, the reconstructed mesh of LOD2 may be determined according to the subdivided mesh on LOD1 and the displacement coefficients of LOD1, and so on, until the reconstructed mesh of LODL is obtained, indicating that the current mesh reconstruction is completed. In FIG. 20, a black solid line (composed of vertices PB_1, PB_2, and PB_3) represents a base mesh, a black dashed line represents a subdivided mesh, the first thick solid line is LOD1 onto which the displacements are applied, and the second thick solid line is LOD2 onto which the displacements are applied.

[0211] In some embodiments, the detailed flow of recursive subdivision is shown in FIG. 21, and the detailed flow may include the following steps.

[0212] In step S1901, firstly, an original mesh is decimated to obtain a base mesh. In step S1902, the base mesh is quantized. In step S1903, the quantized base mesh is encoded. In step S1904, the bitstream is parsed to decode the base mesh from the bitstream to obtain a reconstructed base mesh. In step S1905, n = 0 is initialized, and the reconstructed base mesh is subdivided as an interim mesh. In step S1906, displacement coefficients are calculated from the subdivided mesh and the original mesh. In step S1907, the interim mesh is updated according to the displacement coefficients and the subdivided mesh, and the displacement coefficients are saved to the memory. In step S1909, it is determined whether n is less than L-1. If the determination result in step S1909 is YES, that is, n < L-1, then n = n+1 (S1910), and then steps S1905 to S1909 are continued. If the determination result of step S1909 is NO, that is, n < L−1 is not established, the subdivision is completed. Finally, the displacement coefficients are encoded into the bitstream.

[0213] Thus, in an embodiment of the present disclosure, in the case where the first syntax element indicates that the current mesh adopts a non-linear subdivision mode, as shown in FIG. 22, the base mesh is subdivided first, and an initial subdivided mesh can be obtained. After the displacement coefficients of the initial subdivided mesh are decoded, a corresponding displacement operation is carried out on the vertex coordinate information of the initial subdivided mesh according to the displacement coefficients, and the reconstructed mesh of the first LOD, that is, the reconstructed mesh of LOD1, can be obtained. Then, the reconstructed mesh is subdivided based on LOD1 to obtain a subdivided mesh on LOD1. Then, after decoding the displacement coefficients of LOD1, the reconstructed mesh of LOD2 may be determined according to the subdivided mesh on LOD1 and the displacement coefficients of LOD1. For reconstructed meshes from LOD 3 to LOD L, such as LOD i (i is greater than a preset value, the preset value may be for example 2), the displacement coefficients of neighboring vertices (first points) of the base mesh in LOD i may be set to 0, while the displacement coefficients of other points (second points) may still be decoded. According to the subdivided meshes on LOD i and the displacement coefficients of LOD i, the next LOD of reconstructed meshes may be determined, and so on, until a reconstructed mesh of LOD L is obtained, indicating that the current mesh reconstruction is completed. In FIG. 22, a black solid line (composed of vertices PB_1, PB_2, and PB_3) represents a base mesh, a black dashed line represents a subdivided mesh, a first thick solid line is LOD1 onto which the displacements are applied, and a second thick solid line is LOD2 onto which the displacements are applied. . Although the preset value may be for example 2, the embodiments are not limited thereto. In various embodiments, the preset value may be 2, 3, 4, …, or any other integer value.

[0214] In some embodiments, the detailed flow of non-linear subdivision is shown in FIG. 23, and the detailed flow may include the following steps.

[0215] In step S1901, an original mesh is decimated to obtain the base mesh. In step S1902, the base mesh is quantized. In step S1903, the quantized base mesh is encoded. In step S1904, the bitstream is parsed to decode the base mesh from the bitstream to obtain a reconstructed base mesh. In step S1905, n = 0 is initialized, and the reconstructed base mesh is subdivided as an interim mesh. In step S1906, the displacement coefficient is calculated from the subdivided mesh and the original mesh. In step S1911, the displacement coefficients of adjacent foundation mesh vertices are deleted in order to de-redundancy. In step S1907, the interim mesh is updated according to the displacement coefficient and the subdivided mesh. In step S1908, the other displacement coefficients are saved to the memory. In step S1909, it is determined whether n is less than L-1. If the result of the determination in step S1909 is yes, that is, n < L-1, then n = n+1 (S1910), and then the execution of S1905 to S1909 continues. If the determination result in step S1909 is NO, that is, n < L−1 is not established, the subdivision is completed. Finally, other displacement coefficients need to be encoded into the bitstream.

[0216] That is, in an embodiment of the present disclosure, when LoD is greater than 2, and asps_vdmc_ext_subdivision_method is 3, the displacements that belong to the edge that contains base mesh vertex are inferred to be equal to zero and added to a responding position in the disposition list for mesh reconstruction.

[0217] It is also understandable that when the current mesh does not adopt recursive subdivision, the current mesh can adopt midpoint subdivision at this time. In some embodiments, as shown in FIG. 24, the method may include the following steps.

[0218] In step 201, when the first syntax element indicates that the current mesh adopts the midpoint subdivision mode, the bitstream is decoded to determine the reconstructed base mesh.

[0219] In step 202, the reconstruction base mesh is subdivided to determine a subdivided mesh for at least one LOD of the current mesh.

[0220] In step 203, the bitstream is decoded to determine a displacement coefficient for at least one LOD in the current mesh.

[0221] In step 204, a reconstructed mesh of at least one LOD in the current mesh is determined based on a subdivided mesh of at least one LOD in the current mesh and displacement coefficients of at least one LOD.

[0222] It is to be noted that, in an embodiment of the present disclosure, the number of LODs of at least one LOD is correlated with the number of subdivision iterations of the current mesh. Here, L denotes the number of LODs of at least one LOD, that is, the number of LODs corresponding to the current mesh, which may be equal to a value indicated by asps_vmc_ext_subdivision_iteration_count in the bitstream.

[0223] It is also to be noted that in an embodiment of the present disclosure, as shown in FIGS. 5 and 6, when the midpoint subdivision method is used in the current mesh, the displacement coefficient of each LOD is calculated by the displacement of the vertex coordinate information of the subdivided mesh and the vertex coordinate information of the original mesh, instead of being recursively obtained based on the previously reconstructed LOD.

[0224] An embodiment of the present disclosure provides a decoding method, in particular, a recursive subdivision method of a dynamic mesh. In the embodiment of the present disclosure, by adding a first syntax element indicating that the current mesh adopts a non-linear subdivision method, the displacement coefficient close to the vertex in the base layer is inferred to be equal to 0 in the decoding stage, so that in the subsequent process of recursively applying the displacement coefficient to the previously reconstructed LOD, the redundancy problem of the displacement coefficient at the higher levels can be improved, the encoded bits of the displacement coefficient can be saved, and the encoding and decoding efficiency can be improved.

[0225] In another embodiment of the present disclosure, FIG. 25 is a flowchart of an encoding method provided in an embodiment of the present disclosure. As shown in FIG. 25, the method may include the following steps.

[0226] In step 301, when the non-linear subdivision mode is adopted in the current mesh, the value of the first syntax element is determined, and the first syntax element is written into the bitstream, the reconstructed mesh of the current LOD in the current mesh is determined, and the reconstructed mesh of the current LOD is subdivided, and the subdivided mesh of the current LOD is determined.

[0227] It is to be noted that, in an embodiment of the present disclosure, the encoding method may be a mesh subdivision method, in particular, a recursive subdivision method for dynamic mesh encoding, which can improve the encoding and decoding efficiency.

[0228] It is also to be noted that, in an embodiment of the present disclosure, Video-based Dynamic Mesh Coding (VDMC) is a standard for compressing three-dimensional meshes, which mainly compresses three-dimensional meshes using an existing video-based Visual Volumetric Video-based Coding (V3C) standard. In an embodiment of the present disclosure, the subdivision method shares functionality across all LODs and is defined by two syntax elements asps_vdmc_ext_subdivision_method and asps_vdmc_ext_subdivision_iteration_count in the Atlas sequence parameter set VDMC extension RBSP syntax structure.

[0229] For mesh subdivision, due to the particularity of subdivision, higher-level LOD usually degenerates to a "0" displacement, thus introducing significant redundancy in signaling and coding information. Based on this, in order to efficiently encode the geometry components of the mesh representation of the volumetric content, redundant displacements in cases such as edges of the base mesh and inherited values from the previous LOD can be removed. Embodiments of the present disclosure propose a new adaptive subdivision scheme in which the edge neighboring the base point is always equal to 0 at higher LODs.

[0230] In an embodiment of the present disclosure, it is possible to indicate whether the current mesh adopts a non-linear subdivision mode by setting a first syntax element. The first syntax element herein may be represented by asps_vdmc_ext_subdivision_method for indicating the subdivision method of the mesh. For example, as shown in Table 2, if the value of the first syntax element is 0, it means that the current mesh does not adopt the subdivision mode; and if the value of the first syntax element is 1, it means that the current mesh adopts the midpoint subdivision method.

[0231] It will be appreciated that in an embodiment of the present disclosure, on the basis of Table 2 above, new values are added for the first syntax element so that the first syntax element can be used to indicate whether the current mesh adopts a non-linear subdivision method. Here, the non-linear subdivision may be to create the same subdivision as in the related arts, but the displacement neighboring the base point (e.g., PB_1, PB_2, and PB_3) is inferred to be equal to 0. Simply put, for each LOD, the displacements are calculated based on the subdivision vertices in the previously reconstructed LOD, so that the displacements can be recursively used for the previously reconstructed LOD. In other words, the adaptive subdivision method here is called "Recursive subdivision method". Taking midpoint subdivision as an example, this recursive subdivision method may be called midpoint recursive subdivision method.

[0232] In a possible implementation, as shown in Table 5 as above, a new asps_vdmc_ext_subdivision_method equal to 2 and 3 are added, the new asps_vdmc_ext_subdivision_method would create same subdivision as that in the related arts. However, the displacements neighboring base point (e.g., PB_1, PB_2, and PB_3) are inferred to be equal to zero, thereby saving the coded bits of the displacements.

[0233] It is to be noted that, in an embodiment of the present disclosure, the first syntax element indicates whether the current mesh adopts a non-linear subdivision mode. In some embodiments, the method may include determining a value of a first syntax element. The value of the first syntax element is encoded, and the encoded bits are written into the bitstream.

[0234] It is to be noted that in an embodiment of the present disclosure, if the current mesh adopts a non-linear subdivision method, it can be determined that the value of the first syntax element is a fourth value.

[0235] In a particular embodiment, when the current mesh does not adopt the subdivision mode, it is determined that the value of the first syntax element is a first value. When the current mesh adopts the midpoint subdivision mode, it is determined that the value of the first syntax element is a second value. When the current mesh adopts the recursive subdivision mode, it is determined that the value of the first syntax element is a third value. When the current mesh adopts the non-linear subdivision mode, it is determined that the value of the first syntax element is a fourth value.

[0236] Here, the first value, the second value, the third value, and the fourth value are different from each other. For example, the first value may be set to 0, the second value may be set to 1, the third value may be set to 2, and the fourth value may be set to 3. That is, according to the different values of the first syntax element, it is possible to determine whether the current mesh adopts a non-linear subdivision method.

[0237] In an embodiment, if the value of the first syntax element is 0, it may be determined that the current mesh does not adopt any subdivision, such as midpoint subdivision, recursive subdivision, or nonlinear subdivision. If the value of the first syntax element is 1, it may be determined that the current mesh adopts midpoint subdivision. If the value of the first syntax element is 2, it may be determined that the current mesh is subdivided recursively. If the value of the first syntax element is 3, it may be determined that the current mesh adopts a non-linear subdivision.

[0238] It is also to be noted that in an embodiment of the present disclosure, when the non-linear subdivision method is adopted for the current mesh, the reconstructed mesh of the current mesh may be obtained by recursive reconstruction of at least one LOD. Specifically, after obtaining the reconstructed mesh of the current LOD in the current mesh, the reconstructed mesh of the current LOD may be subdivided to determine the subdivided mesh of the current LOD. Then, a reconstructed mesh of the next LOD of the current LOD may be recursively obtained according to the subdivided mesh, and preset displacement coefficients or the displacement coefficients in the bitstream.

[0239] In some embodiments, a reconstructed mesh of the first LOD of the current mesh is first determined. The method may include: determining a base mesh of a current mesh; encoding and decoding the base mesh to determine a reconstructed base mesh; subdividing the reconstructed base mesh to determine the initial subdivided mesh; determining displacement coefficients of the initial subdivided mesh; and determining the reconstructed mesh of the first LOD in the current mesh is determined according to the initial subdivided mesh and the displacement coefficients of the initial subdivided mesh.

[0240] In an embodiment of the present disclosure, the base mesh may also be referred to as a "decimated mesh". In some embodiments, determining the base mesh of the current mesh may include determining an original mesh of the current mesh; and obtaining the base mesh by downsampling the original mesh.

[0241] It is also noted that in an embodiment of the present disclosure, the current input mesh may be referred to as the original mesh. The base mesh may be obtained by downsampling the input mesh, that is, a simplifying operation of the input mesh may be realized.

[0242] In some embodiments, the method may also include encoding the base mesh and writing the resulting encoded bits into the bitstream.

[0243] For example, the bitstream herein may refer to the base mesh bitstream. Then the base mesh may be written into the base mesh bitstream by a mesh encoder (e.g. EdgeBreaker, etc.).

[0244] In some embodiments, for determining the displacement coefficients of the initial subdivided mesh, the method may include: performing a displacement calculation on the vertex coordinate information of the initial subdivided mesh and the vertex coordinate information of the original mesh to determine the displacement coefficients of the initial subdivided mesh.

[0245] In some embodiments, after determining the reconstructed mesh of the first LOD in the current mesh, the reconstructed mesh of the first LOD is subdivided to determine a subdivided mesh of the second LOD, the bitstream is decoded to determine displacement coefficients of the subdivided mesh of the seond LOD, a reconstructed mesh of a next LOD of the current mesh is determined according to the subdivided mesh of the second LOD and the displacement coefficients of the subdivided mesh of the second LOD, andsubdivision operation is continued, until the reconstructed mesh of the L-th LOD in the current mesh is determined. The value of L is correlated with the number of subdivision iterations of the current mesh.

[0246] In an embodiment of the present disclosure, for the first LOD, the displacement coefficient refers to the difference between the vertex coordinate information of the original mesh and the vertex coordinate information of the initial subdivided mesh. In this way, after the displacement coefficients of the initial subdivided mesh are decoded, the corresponding displacement operation is performed on the vertex coordinate information of the initial subdivided mesh according to the displacement coefficients, to obtain a reconstructed mesh of the first LOD, that is, a reconstructed mesh of LOD1. Then, the reconstructed mesh is subdivided based on LOD1 to obtain the subdivided mesh on LOD1, and then the reconstructed mesh of LOD2 is determined according to the displacement coefficients and the subdivided mesh, and so on until the reconstruction is completed.

[0247] In step 302, when the current LOD is the i-th LOD, the displacement coefficients of the first points of the current LOD are determined to be 0. Here, i is an integer greater than 2. The first points include vertices of the reconstructed base mesh corresponding to the current mesh.

[0248] It is to be noted that, in an embodiment of the present disclosure, the displacement coefficients may include displacement components in one or more directions, and as shown in FIG. 3, the displacement coefficients include displacement components in three directions, namely, the normal direction, the tangent direction, and the bitangent direction. Here, the displacement coefficients of the first LOD are calculated relative to the subdivision vertices of the base mesh, and the displacement coefficients of the subsequent LODs are calculated relative to the subdivision vertices of the reconstructed LOD of the previous LOD, so that the recursive subdivision of the displacement coefficients can be realized.

[0249] It is to be noted that in an embodiment of the present disclosure, if the current LOD is the i-th LOD and i is an integer greater than 2, that is, the current LOD satisfies that LoD is greater than 2, then the displacement coefficients of the first points of the current LOD can be determined to be 0.

[0250] It is to be noted that, in embodiments of the present disclosure, the first points of the current LOD include vertices of the reconstructed base mesh corresponding to the current mesh, that is, the first point may be understood as points coinciding with or neighboring the base point (e.g., PB_1, PB_2, PB_3).

[0251] That is, in an embodiment of the present disclosure, if the first syntax element indicates that the current mesh adopts a non-linear subdivision mode, and the current LOD is greater than 2, then the displacement coefficients of the first points of the current LOD can be directly set to 0, and subsequent mesh reconstruction can be carried out using the displacement coefficients.

[0252] In step 303, a reconstructed mesh of the next LOD in the current mesh is determined based on the subdivided mesh of the current LOD and the displacement coefficients of the first points of the current LOD.

[0253] It is to be noted that in an embodiment of the present disclosure, according to the subdivided mesh of the current LOD and the displacement coefficients of the first points of the current LOD, the reconstructed mesh of the next LOD in the current mesh is determined, which may include: a corresponding displacement operation is performed on the vertex coordinate information of the subdivided mesh of the current LOD according to the displacement coefficients of the first point,, to obtain a reconstructed mesh of the next LOD in the current mesh.

[0254] That is to say, in an embodiment of the present disclosure, the displacement coefficients are recursively applied to the previously reconstructed LOD, in particular, a corresponding displacement coefficient is added to each vertex of the subdivided mesh of the current LOD in order, so that the reconstructed mesh of the next LOD can be obtained.

[0255] It can be understood that in an embodiment of the present disclosure, when the first syntax element indicates that the current mesh adopts a nonlinear subdivision mode, if the current LOD is greater than 2, then the displacement coefficients of the first points of the current LOD are set to 0, that is, the displacements of the points (first points) overlapping or neighboring the base point are set to 0. At this time, in the process of obtaining a reconstructed mesh, the displacement calculation for the first point is actually carried out on the subdivided mesh of the current LOD and 0.

[0256] In some embodiments, the method may further include: after determining the reconstructed mesh of the next LOD in the current mesh, taking the reconstructed mesh of the next LOD as the reconstructed mesh of the current LOD, returning to performing the step of subdividing the reconstructed mesh of the current LOD, and determining the subdivided mesh of the current LOD until the reconstructed mesh of the L-th LOD in the current mesh is determined. The value of L is correlated with the number of subdivision iterations of the current mesh.

[0257] It is also to be noted that in an embodiment of the present disclosure, the number of subdivision iterations of the current mesh may be indicated by a second syntax element in the bitstream. In an embodiment, the method may include decoding a bitstream to determine a value of a second syntax element; and determining the number of subdivision iterations of the current mesh according to the value of the second syntax element.

[0258] In an embodiment of the present disclosure, the second syntax element may be represented by asps_vmc_ext_subdivision_iteration_count. That is, the number of subdivision iterations for the current mesh may be a value indicated by asps_vmc_ext_subdivision_iteration_count in the bitstream.

[0259] In addition, L represents the number of LODs corresponding to the current mesh, and the value of L may be determined by the number of subdivision iterations of the current mesh, that is, the value of L is equal to the value indicated by asps_vmc_ext_subdivision_iteration_count.

[0260] Furthermore, in an embodiment of the present disclosure, FIG. 26 is a second flowchart of an encoding method provided in embodiments of the present disclosure. As shown in FIG. 26, after step 301, the method may include the following steps.

[0261] In step 304, when the current LOD is the i-th LOD, the displacement coefficients of the second points of the current LOD are determined, and the displacement coefficients of the second points are written into the bitstream. Here, the second points do not include the vertices of the reconstructed base mesh corresponding to the current mesh. In other words, the second points are points of the reconstructed base mesh corresponding to the current mesh except the first points.

[0262] It is to be noted that in an embodiment of the present disclosure, if the current LOD is the i-th LOD and i is an integer greater than 2, that is, the current LOD is greater than 2, then the displacement coefficients of the first points of the current LOD may be determined to be 0, and the displacement coefficients of the second points may be obtained by the corresponding position displacement operation, and then the displacement coefficients of the second points may be written into the bitstream. Here, the bitstream may be a displacement bitstream. There are also a variety of specific coding methods for the displacement bitstream, such as video coding, entropy coding and so on. That is, in embodiments of the present disclosure, the displacement information may be written into the displacement bitstream using a video encoder, or the displacement information may be written into the displacement bitstream using an entropy encoder, without any limitation herein.

[0263] In some embodiments, determining the displacement coefficients of the second points of the current LOD may include calculating the displacement of the vertex coordinate information of the subdivided mesh of the current LOD and the vertex coordinate information of the original mesh to determine the displacement coefficients of the second points of the current LOD.

[0264] Further, in some embodiments, the method may further include: preprocessing the displacement coefficients of the second points of the current LOD to determine the quantized displacement coefficients of the second points of the current LOD. The quantized displacement coefficients of the second point of the current LOD are encoded, and the obtained encoded bits are written into the bitstream.

[0265] It is to be noted that, in embodiments of the present disclosure, the second points of the current LOD do not include vertices of the reconstructed base mesh corresponding to the current mesh. In other words, the second points are points of the reconstructed base mesh corresponding to the current mesh except the first points. That is, the second points may be understood as points that are not close to the base point (e.g., PB_1, PB_2, PB_3).

[0266] That is, in an embodiment of the present disclosure, if the current mesh adopts a non-linear subdivision method, and the current LOD is greater than 2, the displacement coefficients of the first points of the current LOD may be set to 0, and at the same time, the displacement coefficients of the second points of the current LOD may be determined by calculation, and the displacement coefficients of the second points may be encoded.

[0267] In step 305, a reconstructed mesh of the next LOD in the current mesh is determined according to the subdivided mesh of the current LOD and the displacement coefficients of the second points of the current LOD.

[0268] It is to be noted that in an embodiment of the present disclosure, the reconstructed mesh of the next LOD in the current mesh is determined according to the subdivided mesh of the current LOD and the displacement coefficients of the second points of the current LOD, specifically, a corresponding displacement operation is performed on the vertex coordinate information of the subdivided mesh of the current LOD according to the displacement coefficients of the second points to obtain a reconstructed mesh of the next LOD in the current mesh.

[0269] That is to say, in an embodiment of the present disclosure, the displacement coefficients are recursively applied to the previously reconstructed LOD, in particular, the displacement coefficients are added to respective vertices of the subdivided mesh of the current LOD in order, so that the reconstructed mesh of the next LOD can be obtained.

[0270] Furthermore, in an embodiment of the present disclosure, FIG. 27 is a third flowchart of an encoding method provided in embodiments of the present disclosure. As shown in FIG. 27, after step 301, the method may include the following steps.

[0271] In step 306, when the current LOD is a second LOD, the displacement coefficients of the current LOD are determined and the displacement coefficients of the current LOD are written into the bitstream.

[0272] It is to be noted that, in an embodiment of the present disclosure, if the current LOD is the second LOD, that is, the current LOD is LoD 2, then the displacement coefficients of the current LOD may be determined by a displacement operation, and the displacement coefficients of the current LOD may be written into a bitstream. Here, the bitstream may be a displacement bitstream.

[0273] There are also a variety of specific coding methods for the displacement bitstream, such as video coding, entropy coding and so on. That is, in an embodiment of the present disclosure, the displacement information may be written into the displacement bitstream using a video encoder, or the displacement information may be written into the displacement bitstream using an entropy encoder, without any limitation herein.

[0274] In some embodiments, determining the displacement coefficients of the current LOD may include: calculating the displacements of the vertex coordinate information of the subdivided mesh of the current LOD and the vertex coordinate information of the original mesh to determine the displacement coefficients of the current LOD.

[0275] Further, in some embodiments, the method may further include: preprocessing the displacement coefficients of the current LOD to determine the quantized displacement coefficients of the current LOD; and encoding the quantized displacement coefficients of the current LOD and writing the encoded bits into a bitstream.

[0276] In step 307, a reconstructed mesh of the next LOD in the current mesh is determined based on the subdivided mesh of the current LOD and the displacement coefficients of the current LOD.

[0277] It is to be noted that in an embodiment of the present disclosure, the reconstructed mesh of the next LOD in the current mesh is determined according to the subdivided mesh of the current LOD and the displacement coefficients of the current LOD, specifically, a corresponding displacement operation is performed on the vertex coordinate information of the subdivided mesh of the current LOD according to the displacement coefficients, to obtain a reconstructed mesh of the next LOD in the current mesh.

[0278] That is, in an embodiment of the present disclosure, the displacement coefficients are recursively applied to the previously reconstructed LOD, specifically, the decoded displacement coefficients are added to respective vertices of the subdivided mesh of the current LOD in order, so that the reconstructed mesh of the next LOD can be obtained.

[0279] In some embodiments, the method may further include: after determining the reconstructed mesh of the next LOD in the current mesh, taking the reconstructed mesh of the next LOD as the reconstructed mesh of the current LOD, returning to performing the step of subdividing the reconstructed mesh of the current LOD, and determining the subdivided mesh of the current LOD until the reconstructed mesh of the L-th LOD in the current mesh is determined. The value of L is correlated with the number of subdivision iterations of the current mesh.

[0280] It is also to be noted that in an embodiment of the present disclosure, the number of subdivision iterations of the current mesh may be indicated by a second syntax element in the bitstream. In an embodiment, the method may include decoding a bitstream to determine a value of a second syntax element. According to the value of the second syntax element, the number of subdivision iterations of the current mesh is determined.

[0281] In an embodiment of the present disclosure, the second syntax element may be represented by asps_vmc_ext_subdivision_iteration_count. That is, the number of subdivision iterations for the current mesh may be a value indicated by asps_vmc_ext_subdivision_iteration_count in the bitstream.

[0282] In addition, L represents the number of LODs corresponding to the current mesh, and the value of L may be determined by the number of subdivision iterations of the current mesh, that is, the value of L is equal to the value indicated by asps_vmc_ext_subdivision_iteration_count.

[0283] Furthermore, in an embodiment of the present disclosure, FIG. 28 is a fourth flowchart of an encoding method provided in an embodiment of the present disclosure. As shown in FIG. 28, the method may include the following steps.

[0284] In step 308, when the current mesh adopts a recursive subdivision mode, the value of the first syntax element is determined, and the first syntax element is written into the bitstream, a reconstructed mesh of the current LOD in the current mesh is determined, and the reconstructed mesh of the current LOD is subdivided to determine a subdivided mesh of the current LOD.

[0285] In an embodiment of the present disclosure, it is also possible to indicate whether the current mesh adopts a recursive subdivision mode by setting a first syntax element. The first syntax element herein may be represented by asps_vdmc_ext_subdivision_method for indicating the subdivision method of the mesh. For example, as shown in Table 2, if the value of the first syntax element is 0, it means that the current mesh does not adopt the subdivision mode. If the value of the first syntax element is 1, it means that the current mesh adopts the midpoint subdivision method.

[0286] It will be appreciated that in an embodiment of the present disclosure, on the basis of Table 2 above, new values are added for the first syntax element so that the first syntax element may indicate whether the current mesh is using recursive subdivision. Here, the recursive subdivision may create the same subdivision as that in the related arts, but the displacement neighboring the base point (e.g., PB_1, PB_2, and PB_3) is inferred to be equal to 0. In other words, for each LOD, the displacement is calculated based on the subdivision vertex in the previously reconstructed LOD, so that the displacement can be recursively used for the previously reconstructed LOD. Therefore, the adaptive subdivision method here is called "Recursive subdivision method". Taking midpoint subdivision as an example, the recursive subdivision method may be called midpoint recursive subdivision method.

[0287] In a possible implementation, as shown in Table 5, a new asps_vdmc_ext_subdivision_method equal to 2 and 3 are added, the new asps_vdmc_ext_subdivision_method would create same subdivision as that in the related arts. However, the displacements neighboring base point (e.g., PB_1, PB_2, and PB_3) are inferred to be equal to zero, thereby saving the coded bits of the displacements.

[0288] It is to be noted that, in an embodiment of the present disclosure, the first syntax element indicates whether the current mesh adopts a recursive subdivision mode. In some embodiments, the method may include: determining a value of a first syntax element; and encoding the value of the first syntax element, and writing encoded bits into the bitstream.

[0289] It is to be noted that, in an embodiment of the present disclosure, if the current mesh adopts a recursive subdivision method, it may be determined that the value of the first syntax element is a third value.

[0290] In an embodiment, when the current mesh does not adopt the subdivision mode, it is determined that the value of the first syntax element is a first value; when the current mesh adopts the midpoint subdivision mode, it is determined that the value of the first syntax element is a second value; when the current mesh adopts the recursive subdivision mode, it is determined that the value of the first syntax element is a third value; and when the current mesh adopts a non-linear subdivision mode, it is determined that the value of the first syntax element is a fourth value.

[0291] Here, the first value, the second value, the third value, and the fourth value are different from each other. For example, the first value may be set to 0, the second value may be set to 1, the third value may be set to 2, and the fourth value may be set to 3. That is, according to the different values of the first syntax element, it is possible to determine whether the current mesh adopts a non-linear subdivision method.

[0292] In an embodiment, if the value of the first syntax element is 0, it may be determined that the current mesh does not adopt any subdivision, such as midpoint subdivision, recursive subdivision, nonlinear subdivision, and the like, if the value of the first syntax element is 1, it may be determined that the current mesh adopts midpoint subdivision; if the value of the first syntax element is 2, it may be determined that the current mesh is subdivided recursively; if the value of the first syntax element is 3, it may be determined that the current mesh adopts a non-linear subdivision.

[0293] It is also to be noted that in an embodiment of the present disclosure, when the non-linear subdivision method is adopted for the current mesh, the reconstructed mesh of the current mesh may be obtained by recursive reconstruction of at least one LOD. Specifically, after obtaining the reconstructed mesh of the current LOD in the current mesh, the reconstructed mesh of the current LOD may be subdivided to determine the subdivided mesh of the current LOD. Then, a reconstructed mesh of the next LOD of the current LOD may be recursively obtained according to the subdivided mesh, and preset displacement coefficients or displacement coefficients in the bitstream.

[0294] In some embodiments, a reconstructed mesh of the first LOD of the current mesh is first determined. The method may include: determining a base mesh of a current mesh; encoding and decoding the base mesh to determine a reconstructed base mesh; subdividing the reconstructed base mesh to determine the initial subdivided mesh; determining displacement coefficients of the initial subdivided mesh; and determining the reconstructed mesh of the first LOD in the current mesh is determined according to the initial subdivided mesh and the displacement coefficients of the initial subdivided mesh.

[0295] In an embodiment of the present disclosure, the base mesh may also be referred to as a "decimated mesh". In some embodiments, determining the base mesh of the current mesh may include determining an original mesh of the current mesh; and obtaining the base mesh by downsampling the original mesh.

[0296] It is also noted that in an embodiment of the present disclosure, the current input mesh may be referred to as the original mesh. The base mesh may be obtained by downsampling the input mesh, that is, a simplifying operation of the input mesh may be realized.

[0297] In some embodiments, the method may also include encoding the base mesh and writing the resulting encoded bits into the bitstream.

[0298] For example, the bitstream herein may refer to the base mesh bitstream. Then, the base mesh may be written into the base mesh bitstream by a mesh encoder (e.g. EdgeBreaker, etc.).

[0299] In some embodiments, for determining the displacement coefficients of the initial subdivided mesh, the method may include: performing a displacement calculation on the vertex coordinate information of the initial subdivided mesh and the vertex coordinate information of the original mesh to determine the displacement coefficients of the initial subdivided mesh.

[0300] In an embodiment of the present disclosure, for the first LOD, the displacement coefficient refers to the difference between the vertex coordinate information of the original mesh and the vertex coordinate information of the initial subdivided mesh. In this way, after the displacement coefficient of the initial subdivided mesh is decoded, the corresponding displacement operation is performed on the vertex coordinate information of the initial subdivided mesh according to the displacement coefficient, and the reconstructed mesh of the first LOD, that is, the reconstructed mesh of LOD1, can be obtained. Then, the reconstructed mesh is subdivided based on LOD1 to obtain a subdivided mesh on LOD1, and the reconstructed mesh of LOD2 is determined according to the subdivided mesh and corresponding displacement coefficients, and so on, until the reconstruction is completed.

[0301] In step 309, the displacement coefficients of the current LOD are determined, and the displacement coefficients of the current LOD are written into a bitstream.

[0302] It is to be noted that, in an embodiment of the present disclosure, the displacement coefficients may include displacement components in one or more directions, and as shown in FIG. 3, the displacement coefficients include displacement components in three directions, namely, the normal direction, the tangent direction, and the bitangent direction. Here, the displacement coefficients of the first LOD are calculated relative to the subdivision vertices of the base mesh, and the displacement coefficients of the subsequent LODs are calculated relative to the subdivision vertices of the reconstructed LOD of the previous LOD, so that the recursive subdivision based on the displacement coefficients can be realized.

[0303] In some embodiments, the method for determining the displacement coefficients of the current LOD involved in any one of steps 304, 306, and 309 may specifically include: calculating the displacements of the vertex coordinate information of the subdivided mesh of the current LOD and the vertex coordinate information of the original mesh, and determining the displacement coefficients of the current LOD.

[0304] Further, in some embodiments, the method may further include: preprocessing the displacement coefficients of the current LOD to determine the quantized displacement coefficients of the current LOD; and encoding the quantized displacement coefficients of the current LOD and writing the encoded bits into the bitstream.

[0305] That is, in an embodiment of the present disclosure, after the subdivided mesh is generated, a geometry displacement vector may be calculated for each vertex of the subdivided mesh so that the shape of the subdivided mesh is as close as possible to the shape of the original mesh. These geometry displacement vectors are the displacement coefficients herein. Specifically, there is a difference in the geometry information between the vertices of the subdivided mesh and the vertices of the original mesh, which is the displacement coefficient.

[0306] It is also to be noted that, in an embodiment of the present disclosure, after determining the quantized displacement coefficients of the current LOD, the quantized displacement coefficients of the current LOD are encoded into a bitstream. Here the bitstream may be a displacement bitstream. There are also a variety of specific coding methods for the displacement bitstream, such as video coding, entropy coding and so on. That is, in an embodiment of the present disclosure, the displacement information may be written into the displacement bitstream using video encoder, or the displacement information may be written into the displacement bitstream using an entropy encoder, without any limitation herein.

[0307] It is also to be noted that in an embodiment of the present disclosure, after the displacement coefficients of the current LOD are obtained, the displacement coefficients of the current LOD may be preprocessed. Here, the preprocessing can include wavelet transform, quantization and other processing.

[0308] In an embodiment, preprocessing the displacement coefficients of the current LOD to determine the quantized displacement coefficients of the current LOD may include: performing a wavelet transform on the displacement coefficients of the current LOD to determine the wavelet transform coefficients of the current LOD; and quantizing the wavelet transform coefficients of the current LOD to determine quantized displacement coefficients of the current LOD.

[0309] In an embodiment of the present disclosure, the wavelet transform converts the displacement coefficients of the current LOD into signals in the wavelet domain. Here, the wavelet transform coefficients are calculated in floating-point format. Quantization is to convert a floating-point number into a fixed-point number of preset accuracy. Here, the preset accuracy may be an accuracy indicated in an encoded bitstream at the level of patch, picture, or sequence.

[0310] In some embodiments, quantizing the wavelet transform coefficients of the current LOD to determine the quantized displacement coefficients of the current LOD may include: determining quantization parameters of the current LOD; and quantizing the wavelet transform coefficients of the current LOD according to the quantization parameters of the current LOD, to determine the quantized displacement coefficients of the current LOD.

[0311] It is to be noted that, in an embodiment of the present disclosure, the Quantizer Parameter (QP) reflects the spatial detail compression situation. Here, the smaller the value, the finer the quantization, the higher the image quality, and the longer the bitstream. If the QP is small, most of the details will be retained. If QP increases, some details are lost, bit rate will be reduced, but image distortion is enhanced and quality is degenerated. Specifically, QP is the serial number of a quantization step Qstep. When the value of QP is 0, it means that the quantization is the finest. On the contrary, when the value of QP is 51, it means that the quantization is rougher.

[0312] In some embodiments, determining quantization parameters of the current LOD may include: determining a plurality of candidate quantization parameters for the current LOD; calculating the quantization and coding cost of the wavelet transform coefficients of the current LOD based on the plurality of candidate quantization parameters; and determining the cost results of each of the plurality of candidate quantization parameters; determining the minimum cost result the respective cost results of the plurality of candidate quantization parameters; and determining the candidate quantization parameter corresponding to the minimum cost result as the quantization parameter of the current LOD.

[0313] It is to be noted that in an embodiment of the present disclosure, there may be a plurality of candidate quantization parameters for each LOD, and a candidate quantization parameter corresponding to the minimum cost result is selected from the plurality of candidate quantization parameters according to the respective cost results of the plurality of candidate quantization parameters, and the candidate quantization parameter is used as the quantization parameter of the current LOD. The cost calculation herein may include at least one of: Rate-Distortion Optimization (RDO) Mean Square Error (MSE), Sum of Squared Difference (SSD), Sum of Absolute Difference (SAD), Sum of Absolute Transformed Difference (SATD), Peak Signal to Noise Ratio (PSNR), and the like.

[0314] It is also to be noted that, in an embodiment of the present disclosure, quantization parameters may be represented by vmc_transform_lifting_quantization_parameters [ltpIndex] [i] [j]. Here, the wavelet transform coefficients may be converted into fixed-point representations according to the accuracy indicated in the coded bitstream at patch level, picture level, or sequence level according to the quantization parameter vmc_transform_lifting_quantification_parameters [ltpIndex] [i] [j] of LoD j and the corresponding coordinates i in the bitstream. Here, i represents component information(x, y, z for canonical coordinate systems, n, t, bt for local coordinate systems) of displacement coefficients; j denotes LOD; ltpIndex represents the applied level; 0 represents the sequence level, 1 represents the image level, and 2 represents the patch level.

[0315] In a possible implementation, for the quantization parameters of the current LOD, the method may include encoding the quantization parameters of the current LOD and writing the resulting encoded bits into a bitstream.

[0316] In another possible implementation, for the quantization parameter of the current LOD, the method may include: determining the quantization parameter of the previous LOD of the current LOD; determining the quantization parameter increment of the current LOD according to the quantization parameter of the previous LOD and the quantization parameter of the current LOD; and encoding the quantization parameter increment of the current LOD, and writing the encoded bits into a bitstream.

[0317] That is, in an embodiment of the present disclosure, the encoder side may directly write the quantization parameters into the bitstream, so that the decoder side may obtain the corresponding quantization parameters by decoding. Alternatively, the encoder side may write the quantization parameter increment into the bitstream, and then the decoder side may obtain the corresponding quantization parameter according to the decoded quantization parameter increment and the quantization parameter of the previous LOD.

[0318] In a specific embodiment, the quantization parameter increment of the current LOD may be determined by subtracting the quantization parameter of the current LOD from the quantization parameter of the previous LOD. For example, assuming that the quantization parameter of the current LOD may be represented by QP (i), the quantization parameter of the previous LOD may be represented by QP (i-1), and the quantization parameter increment may be represented by ΔQP, then $\Delta QP = QP(i) - QP(i\text{-}1)$. For the quantization parameter of the first LOD, the corresponding quantization parameter QP (1) may be directly written into the bitstream.

[0319] It is also to be noted that in an embodiment of the present disclosure, a reference quantization parameter may be set at the encoder side and the decoder side, and then the quantization parameter increment between the quantization parameter of each LOD and the reference quantization parameter is written into the bitstream. In this way, after the quantization parameter increment of the current LOD is determined in the decoded bitstream, the decoder side may determine the quantization parameter of the current LOD according to the quantization parameter increment of the current LOD and the reference quantization parameter, so that the coded bits of the quantization parameter in the bitstream can also be saved.

[0320] In some embodiments, the method may further include: determining quantized displacement coefficients of at least one LOD in the current mesh, wherein the at least one LOD includes the current LOD; packing quantized displacement coefficients of at least one LOD into a two-dimensional image according to a preset packing mode; encoding the two-dimensional image, and writing the encoded bits into a bitstream.

[0321] In an embodiment of the present disclosure, the preset packing mode includes a forward packing mode or an inverse packing mode. The determination of the preset packing mode may be that the decoder side and the encoder side set the same packing mode, or may be indicated according to a third syntax element in the bitstream.

[0322] In a specific embodiment, the method may further include: determining a value of a third syntax element according to a preset packing mode; and encoding the value of the third syntax element, and writing the encoded bits into a bitstream.

[0323] In an embodiment of the present disclosure, the third syntax element may be represented by dmsps_packing_order. That is, the preset packing mode may be the packing mode indicated by dmsps_packing_order in the bitstream.

[0324] In this way, if the encoder side compresses the displacements by video encoding, the decoder side decodes the displacements by a corresponding video decoder, and recovers the displacements from the two-dimensional image according to a corresponding order according to the preset packing mode. Then, inverse quantization is performed on the displacements, inverse wavelet transform and other operations are performed to restore the same displacement coefficients as the encoder side. Otherwise, if the encoder side uses entropy coding for the displacement coefficients, the decoder side may directly decode the displacement coefficients using entropy decoding, and then perform subsequent operations such as inverse quantization and inverse wavelet transform to obtain the displacement coefficients of the current LOD.

[0325] For example, FIG. 29A is a schematic diagram of a packing mode of displacement coefficients in a two-dimensional image provided by an embodiment of the present disclosure, and FIG. 29B is a schematic diagram of another packing mode of displacement coefficients in a two-dimensional image provided by an embodiment of the present disclosure. FIG. 29A is an exemplary forward packing mode, or "continuous-packing", and FIG. 29B is an exemplary inverse packing.

[0326] That is, in an embodiments of the present disclosure, for quantized displacement coefficients, the quantized displacement coefficients are scanned along a three-dimensional spatial scanning pattern (e.g., Morton, Hilbert, or along other space filling curve) within each LOD, forming three one-dimensional arrays per each component (see FIGS. 29A and 29B). The quantized displacement coefficients are converted into a two-dimensional image according to LOD and selected packing mode indicated by the syntax element dmsps_packing_order. Here, the unoccupied symbols in the Coding Tree Unit (CTU) may be padded using one of the padding methods (e.g., zero-padding).

[0327] In step 310, a reconstructed mesh of the next LOD in the current mesh is determined based on the subdivided mesh of the current LOD and the displacement coefficients of the current LOD.

[0328] It is to be noted that in an embodiment of the present disclosure, the reconstructed mesh of the next LOD in the current mesh is determined according to the subdivided mesh of the current LOD and the displacement coefficients of the current LOD, specifically, the corresponding displacement operation is performed on the vertex coordinate information of the subdivided mesh of the current LOD according to the displacement coefficients, to obtain a reconstructed mesh of the next LOD in the current mesh.

[0329] That is, in an embodiment of the present disclosure, the displacement coefficients are recursively applied to the previously reconstructed LOD. Specifically, the decoded displacement coefficient is added to each vertex of the subdivided mesh of the current LOD in order, so that the reconstructed mesh of the next LOD can be obtained.

[0330] In some embodiments, the method may further include: after determining the reconstructed mesh of the next LOD in the current mesh, taking the reconstructed mesh of the next LOD as the reconstructed mesh of the current LOD, returning to performing the step of subdividing the reconstructed mesh of the current LOD, and determining the subdivided mesh of the current LOD until the reconstructed mesh of the L-th LOD in the current mesh is determined. The value of L is correlated with the number of subdivision iterations of the current mesh.

[0331] It is also to be noted that in an embodiment of the present disclosure, the number of subdivision iterations of the current mesh may be indicated by a second syntax element in the bitstream. In an embodiment, the method may include: determining the number of subdivision iterations for a current mesh; determining the value of the second syntax element according to the number of subdivision iterations of the current mesh; and encoding the value of the second syntax element, and writing the encoded bits into a bitstream.

[0332] In an embodiment of the present disclosure, the second syntax element may be represented by asps_vmc_ext_subdivision_iteration_count. That is, the number of subdivision iterations for the current mesh may be a value indicated by asps_vmc_ext_subdivision_iteration_count in the bitstream.

[0333] In addition, L represents the number of LODs corresponding to the current mesh, and the value of L may be determined by the number of subdivision iterations of the current mesh, that is, the value of L is equal to the value indicated by asps_vmc_ext_subdivision_iteration_count.

[0334] Thus, in an embodiment of the present disclosure, in the case where the first syntax element indicates that the current mesh adopts a recursive subdivision mode, as shown in FIG. 20, the base mesh is subdivided first, and an initial subdivided mesh may be obtained. After the displacement coefficients of the initial subdivided mesh are decoded, the corresponding displacement operation is carried out on the vertex coordinate information of the initial subdivided mesh according to the displacement coefficients, and the reconstructed mesh of the first LOD, that is, the reconstructed mesh of LOD1, may be obtained. Then, the reconstructed mesh is subdivided based on LOD1 to obtain a subdivided mesh on LOD1. Then, after decoding the displacement coefficients of LOD1, a reconstructed mesh of LOD2 may be determined according to the subdivided mesh on LOD1 and the displacement coefficients of LOD1, and so on, until a reconstructed mesh of LODL is obtained, indicating that the current mesh reconstruction is completed. In FIG. 20, a black solid line (composed of vertices PB_1, PB_2, and PB_3) represents a base mesh, a black dashed line represents a subdivided mesh, the first thick solid line is LOD1 onto which the displacements are applied, and the second thick solid line is LOD2 onto which the displacements are applied.

[0335] In some embodiments, the detailed flow of recursive subdivision is shown in FIG. 21, and the detailed flow may include the following steps.

[0336] In step S1901, the original mesh is decimated to obtain the base mesh. In step S1902, the base mesh is quantized. In step S1903, the quantized base mesh is encoded. In step S1904, a bitstream is parsed to decode the base mesh from the bitstream to obtain a reconstructed base mesh. In step S1905, $n = 0$ is initialized, and the reconstructed base mesh is subdivided as an interim mesh. In step S1906, the displacement coefficients are calculated from the subdivided mesh and the original mesh. In step S1907, the interim mesh is updated according to the displacement coefficients and the subdivided mesh. In step S1908, the displacement coefficients are saved to the memory. In step S1909, it is determined whether n is less than L-1. If the determination result in step S1909 is YES, that is, $n < L-1$, then $n = n+1$ (S1910), and steps S1905 to S1909 are continued. If the determination result in step S1909 is NO, that is, $n < L-1$ is not established, the subdivision is completed. Finally, the displacement coefficients need to be encoded into the bitstream.

[0337] Thus, in an embodiment of the present disclosure, in the case where the first syntax element indicates that the current mesh adopts a non-linear subdivision mode, as shown in FIG. 22, the base mesh is subdivided first, and an initial subdivided mesh may be obtained. After the displacement coefficients of the initial subdivided mesh are decoded, a corresponding displacement operation is carried out on the vertex coordinate information of the initial subdivided mesh according to the displacement coefficients, and the reconstructed mesh of the first LOD, that is, the reconstructed mesh of LOD1, may be obtained. Then, the reconstructed mesh is subdivided based on LOD1 to obtain a subdivided mesh on LOD1. Then, after decoding the displacement coefficients of LOD1, a reconstructed mesh of LOD2 may be determined according to the subdivided mesh on LOD1 and the displacement coefficients of LOD1. For the reconstructed meshes from LOD 3 to LOD L, such as LOD i (i is greater than a preset value, the preset value may be for example 2), the displacement coefficients of neighboring vertices (first points) of the base mesh in LOD i may be set to 0, while the displacement coefficients of other points (second points) may still be decoded. According to the subdivided meshes on LOD i and the displacement coefficients of LOD i, the next LOD of reconstructed meshes may be determined, and so on, until the reconstructed mesh of LOD L is obtained, indicating that the current mesh reconstruction is completed. In FIG. 22, a black solid line (composed of vertices PB_1, PB_2, and PB_3) represents a base mesh, a black dashed line represents a subdivided mesh, a first thick solid line is LOD1 onto which the displacements are applied, and a second thick solid line is LOD2 onto which the displacements are applied. Although the preset value may be for example 2, the embodiments are not limited thereto. In various embodiments, the preset value may be 2, 3, 4, …, or any other integer value.

[0338] In some embodiments, the detailed flow of non-linear subdivision is shown in FIG. 23, and the detailed flow may include the following steps.

[0339] In step S1901, the original mesh is decimated to obtain the base mesh. In step S1902, the base mesh is quantized. In step S1903, the quantized base mesh is encoded. In step S1904, the bitstream is parsed to decode the base mesh from the bitstream to obtain a reconstructed base mesh. In step S1905, $n = 0$ is initialized, and the reconstructed base mesh is subdivided as an interim mesh. In step S1906, displacement coefficients are calculated from the subdivided mesh and the original mesh. In step S1911, the displacement coefficients of adjacent foundation mesh vertices are deleted in order to remove redundancy. In step S1907, the interim mesh is updated according to the displacement coefficients and the subdivided mesh. In step S1908, the other displacement coefficients are saved to the memory. In step S1909, it is determined whether n is less than L-1. If the determination result in step S1909 is YES, that is, $n < L-1$, then $n = n+1$, and then steps S1905 to S1909 are continued. If the determination result in step S1909 is NO, that is, $n < L-1$ is not established, the subdivision is completed. Finally, other displacement coefficients need to be encoded into the bitstream.

[0340] It is also can be understood that when the current mesh does not adopt recursive subdivision, the current mesh can use midpoint subdivision. In some embodiments, the method may include: determining a reconstructed base mesh when the current mesh adopts a midpoint subdivision mode; subdividing the reconstructed base mesh to determine a subdivided mesh of at least one LOD in the current mesh;

determining displacement coefficients of at least one LOD in the current mesh; and determining a reconstructed mesh of at least one LOD in the current mesh according to the subdivided mesh of at least one LOD in the current mesh and the displacement coefficient of at least one LOD.

[0341] It is to be noted that, in an embodiment of the present disclosure, the number of at least one LOD is correlated with the number of subdivision iterations of the current mesh. Here, L denotes the number of LODs of at least one LOD, that is, the number of LODs corresponding to the current mesh, which may be equal to a value indicated by asps_vmc_ext_subdivision_iteration_count in the bitstream.

[0342] It is also to be noted that in an embodiment of the present disclosure, as shown in FIGS. 5 and 6, when the midpoint subdivision method is used in the current mesh, the displacement coefficients of each LOD are calculated by the displacement of the vertex coordinate information of the subdivided mesh and the vertex coordinate information of the original mesh, instead of being recursively obtained based on the previously reconstructed LOD.

[0343] It is also understood that in an embodiment of the present disclosure, there is also provided a bitstream which is generated by bit encoding based on information to be encoded. Here, the information to be encoded includes at least one of type of information including: a base mesh of the current mesh, displacement coefficients of at least one LOD of the current mesh, quantization parameters of at least one LOD of the current mesh, a quantization parameter increment of at least one LOD of the current mesh, a value of a first syntax element, a value of a second syntax element, and a value of a third syntax element.

[0344] An embodiment of the present disclosure provides an encoding method, in particular a recursive subdivision method of a dynamic mesh. In the embodiment of the present disclosure, by adding a first syntax element indicating that the current mesh adopts a nonlinear subdivision method, the displacement coefficient close to the vertex in the base layer can be removed from the displacement list in the coding stage, so that in the subsequent process of recursively applying the displacement coefficient to the previously reconstructed LOD, the redundancy problem of the displacement coefficient at the higher levels can be improved, the coded bits of the displacement coefficient can be saved, and the encoding and decoding efficiency can be improved.

[0345] In yet another embodiment of the present disclosure, based on the encoding and decoding method described in the preceding embodiment, as shown in FIG. 6, displacement coefficients are applied to a previously reconstructed LOD. In some cases, displacement coefficients are often redundant at higher LODs.

[0346] In some systems, the subdivision method shares functionality across all LODs and is defined by the two syntax elements asps_VDMC_ext_subdivision_method and asps_VDMC_ext_subdivision_iteration_count in the Atlas sequence parameter set VDMC extension RBSP syntax structure, as shown in Table 1 above.

[0347] Asps_vdmc_ext_subdivision_method indicates the subdivision method identifier of the mesh associated with the current atlas sequence parameter set. Table 2 above describes the list of supported subdivision methods and their relationship to asps_vdmc_ext_subdivision_method.

[0348] Asps_vdmc_ext_subdivision_iteration_count indicates the number of subdivision iterations for the mesh. When asps_vdmc_ext_subdivision_iteration_count is not present, the value of asps_vdmc_ext_subdivision_iteration_count is inferred to be equal to 0.

[0349] Due to the specialty of subdivision, displacements at higher LODs often degenerate to "0", introducing significant redundancy in signaling and coding information. The proposed solution of the embodiments of the present disclosure introduces an efficient and flexible method and apparatus for efficient coding of the geometry component of the mesh representation of the volumetric content by removing redundant displacements in cases such as base mesh edge and inheriting value from previous LOD.

[0350] To overcome the issue of signaling the degenerated edge, an embodiment of the present disclosure propose a new adaptive subdivision method whereas edges that are adjacent to the base points at higher LODs shall be always equal to 0. One way of implementing this is by adding a new asps_vdmc_ext_subdivision_method equal to 2 and 3. That would create the same subdivision as that in the related arts. However, the displacements neighboring base points (e.g., PB_1, PB_2, and PB_3) is inferred to be equal to zero, as shown in FIGS. 20, 21, 22 and 23.

[0351] In an embodiment, a method of efficiently encoding geometry displacement coefficients in a mesh by an encoder side includes a subdivision process with recursive subdivision updates, where the displacement coefficients are calculated relative to subdivision vertices in a previously reconstructed LOD.

[0352] Stage 1. Mesh segmentation is a step that creates segments or blocks of mesh content representing individual objects/regions of interest/volumetric tiles, semantic blocks, etc. The number of LOD subdivisions is defined by asps_vmc_ext_subdivision_iteration_count.

[0353] Stage 2. Mesh decimation creates a base mesh, and the base mesh is coded with an undefined static mesh encoder. The base mesh is decoded and recursively subdivided to the number of LOD.

[0354] Stage 3. Mesh displacements are calculated between the previous updated subdivided LOD for mesh and the original surface for mesh for each LOD. The displacements are then processed with a wavelet transform.

[0355] When LoD is greater than 2, and the value of syntax element asps_vdmc_ext_subdivision_method is equal to 3 the displacements that belong to the edge that contains base mesh vertex are inferred to be equal to zero and are not recorded in the displacement list for further coding.

[0356] Stage 4. Wavelet transform coefficients are converted to a fix-point representation with a precision indicated in the coded bitstream at either patch, picture, or sequence level (ltpIndex) depending on the quantization parameter vmc_transform_lifting_quantization_parameters[ltpIndex][i][j] for a corresponding coordinate I and LOD j as signaled in the bitstream.

[0357] Stage 5. The quantized wavelet coefficients are scanned along a 3d space scanning pattern (e.g. Morton, Hilbert, or along other space filling curve) within each LoD, forming three 1-dimensional arrays per each component (FIGS. 29A and 29B).

[0358] The coefficients are converted to a two-dimensional image according to LoD and selected packing order indicated by a flag dmsps_packing_order. The unoccupied symbols in CTU are padded using one of the padding methods (e.g. zero-padding).

[0359] In an embodiment, the decoding process is the inverse of the encoding process and includes the following stages.

[0360] Stage 1. The base mesh is decoded from geometry bitstream and recursively subdivided to the LOD defined by the encoder.

[0361] Stage 2. A coded bitstream for geometry displacements is obtained and decoded with a codec responding to the dmsps_mesh_codec_id decoder.

[0362] Stage 3. The displacement wavelet coefficients are dequantized using the quantization parameter signaled in the bitstream.

[0363] Stage 4. The dequantized disposition wavelet coefficients are processed with an inverse wavelet transform.

[0364] Stage 5. Mesh displacements are applied to the subdivided base mesh at each transform level recurrent to generate the reconstructed mesh consistent of blocks presenting individual objects/regions of interest/volumetric tiles, semantic blocks, etc.

[0365] In other words, in an embodiment of the present disclosure, when LoD is greater than 2, and asps_vdmc_ext_subdivision_method is 3 the displacements that belongs to the edge that contains base mesh vertex are inferred to be equal to zero and added to a responding position in the disposition list for mesh reconstruction.

[0366] The specific implementations of the aforementioned embodiments are described in detail through the aforementioned embodiments, from which it can be seen that according to the technical proposal of the aforementioned embodiments, when it is determined that the current mesh adopts the nonlinear subdivision mode by adding a first syntax element to indicate that the current mesh adopts the nonlinear subdivision mode, the reconstructed mesh of the current LOD in the current mesh is subdivided, and the subdivided mesh of the current LOD is determined, the displacement coefficients of the first points (points coinciding with or neighboring the base point) of the current LOD are directly set to 0, that is, the displacements neighboring the base point (e.g., PB_1, PB_2, and PB_3) is inferred to be equal to 0, the reconstructed mesh of the next LOD in the current mesh is determined according to the subdivided mesh of the current LOD and the displacement coefficient of the current LOD. In this way, when the non-linear subdivision method is used in the current mesh, the redundancy problem of the displacement coefficients in the higher LODs can be further improved, the coded bits of the displacement coefficients can be saved, and the encoding and decoding efficiency can be improved.

[0367] That is, in an embodiment of the present disclosure, by adding a first syntax element indicating that the current mesh adopts a non-linear subdivision method, the displacement coefficient close to the vertex in the base layer can be removed from the displacement list in the encoding stage, and the displacement coefficient close to the vertex in the base layer is inferred to be equal to 0 in the decoding stage. Therefore, in the subsequent process of recursively applying the displacement coefficient to the previously reconstructed LOD, the redundancy problem of the displacement coefficient at the higher LODs can be improved, the coded bits of the displacement coefficient can be saved, and the encoding and decoding efficiency can be improved.

[0368] In another embodiment of the present disclosure, based on the same invention concept as the foregoing embodiment, FIG. 30 is a schematic diagram of a structure of an encoder provided in an embodiment of the present disclosure. As shown in FIG. 30, the encoder 300 may include a first determination unit 3001.

[0369] The first determination unit 3001 is configured to: determine a value of a first syntax element when the current mesh adopts a non-linear subdivision mode; write the first syntax element into a bitstream; determine a reconstructed mesh of a current LOD in the current mesh; subdivide the reconstructed mesh of the current LOD to determine a subdivided mesh of the current LOD; determine displacement coefficients of the first points of the current LOD as 0 when the current LOD is an i-th LOD, and determine a reconstructed mesh of a next LOD in the current mesh based on a subdivided mesh of the current LOD and displacement coefficients of the current LOD. Here, i is an integer greater than 2, the first points include vertices of a reconstructed base mesh corresponding to the current mesh.

[0370] It can be understood that in embodiments of the present disclosure, the "unit" may be a partial circuit, a partial processor, a partial program or software, etc., and of course may be a module, or may be non-modular. Moreover, the components in this embodiment may be integrated in one processing unit, each unit may exist physically individually, or two or more units may be integrated in one unit. The integrated unit can be realized in the form of hardware or in the form of software function modules.

[0371] The integrated units may be stored in a computer-readable storage medium if implemented in the form of software functional modules and not sold or used as stand-alone products. Based on this understanding, the technical solution of the present embodiment may be embodied in the form of a software product, which is stored in a storage medium and includes a number of instructions to cause a computer device (may be a personal computer, server, network device, etc.) or a processor (processor) to perform all or part of the steps of the method described in the present embodiment. The aforementioned storage medium includes various media that can store program codes, such as a U disk, a mobile hard disk, a Read Only Memory (ROM), a Random Access Memory (RAM), a magnetic disk, or an optical disk.

[0372] Accordingly, embodiments of the present disclosure provide a computer-readable storage medium, applied to an encoder 300, that stores a computer program that, when executed by a first processor, implements the method described in any of the preceding embodiments.

[0373] Based on the composition of the encoder 300 and the computer-readable storage medium, FIG. 31 is a schematic diagram of a specific hardware structure of an encoder provided in an embodiment of the present disclosure. As shown in FIG. 31, the encoder 300 may include a first communication interface 3101, a first memory 3102, and a first processor 3103. The components are coupled together via a first bus system 3104. It can be understood that the first bus system 3104 is used to implement connection communication between these components. The first bus system 3104 includes a data bus, a power bus, a control bus, and a status signal bus. However, for the sake of clarity, the various buses are labeled in FIG. 31 as the first bus system 3104.

[0374] The first communication interface 3101 is configured to receive and transmit signals in the process of transmitting and receiving information with other external network elements.

[0375] The first memory 3102 is configured to store computer programs capable of running on the first processor 3103.

[0376] The first processor 3103 is configured to: when running the computer program, perform operations of: when a current mesh adopts a nonlinear subdivision mode, determining a value of a first syntax element, writing the first syntax element into a bitstream, determining a reconstructed mesh of a current LOD in the current mesh, and subdividing the reconstructed mesh of the current LOD to determine a subdivided mesh of the current LOD; when the current LOD is an i-th LOD, determining displacement coefficients of first points of the current LOD as 0, wherein i is an integer greater than 2, and the first points include vertices of a reconstructed base mesh corresponding to the current mesh; and determining a reconstructed mesh of a next LOD in the current mesh according to the subdivided mesh of the current LOD and the displacement coefficients of the first points of the current LOD.

[0377] It will be appreciated that the first memory 3102 in an embodiment of the present disclosure, may be volatile memory or non-volatile memory, or may include both volatile and non-volatile memory. The non-volatile memory may be a Read-Only Memory (ROM), a Programmable ROM (PROM), an Erasable PROM (EPROM), an Electrically Erasable EPROM (EEPROM), or a Flash memory. The volatile memory may be a Random Access Memory (RAM), which serves as an external cache. By way of exemplary, but not limiting, description, many forms of RAM are available, such as Static RAM (SRAM), Dynamic RAM (DRAM), Synchronous DRAM (SDRAM), Double Data Rate Synchronous Dynamic RAM (DDRSDRAM), Enhanced Synchronous Dynamic RAM (ESDRAM), Synchlink DRAM (SLDRAM), and Direct Memory Bus RAM (DRRAM). The first memory 3102 of the systems and methods described in the present disclosure is intended to include, but is not limited to, these and any other suitable types of memory.

[0378] The first processor 3103 may be an integrated circuit chip having signal processing capability. In implementation, various steps of the method described above may be completed by integrated logic circuits of hardware in the first processor 3103 or by instructions in the form of software. The first processor 3103 may be a general purpose processor, a Digital Signal Processor (DSP), an Application

Specific Integrated Circuit (ASIC), an off-the-shelf programmable gate array (FPGA) or other programmable logic device, a discrete gate or transistor logic device, or a discrete hardware component. The disclosed methods, steps, and logical block diagrams in an embodiment of the present disclosure, may be implemented or executed. The general purpose processor may be a microprocessor or the processor may be any conventional processor or the like. The steps of the method disclosed in combination with the embodiments of the present disclosure can be directly reflected as the completion of execution by a hardware decoding processor, or the completion of execution by combining hardware and software modules in the decoding processor. Software modules can be located in memory media mature in the art, such as random access memory, flash memory, read-only memory, programmable read-only memory or electrically erasable programmable memory, registers, etc. The storage medium is located in the first memory 3102, and the first processor 3103 reads the information in the first memory 3102, and completes the steps of the above method in combination with its hardware.

[0379] It will be appreciated that these embodiments described in the present disclosure may be implemented with hardware software firmware middleware microcode or a combination thereof. For hardware implementation, the processing unit may be implemented in one or more Application Specific Integrated Circuits (ASICs), Digital Signal Processors (DSPDs), Digital Signal Processing Devices (DSPDs), Programmable Logic Devices (PLDs), Field-Programmable Gate Arrays (FPGAs), general purpose processors, controllers, microcontrollers, microprocessors, other electronic units for performing functions described in the present disclosure, or combinations thereof. For software implementations, the techniques described in the present disclosure may be implemented by modules (e.g., processes, functions, etc.) that perform the functions described in the present disclosure. Software code may be stored in memory and executed by the processor. The memory may be implemented in the processor or outside the processor.

[0380] Optionally, as another embodiment, the first processor 3103 is also configured to execute the method described in any of the preceding embodiments when running the computer program.

[0381] The present embodiment provides an encoder. In the encoder, by adding a first syntax element indicating that a current mesh adopts a nonlinear subdivision mode, when it is determined that the current mesh adopts a nonlinear subdivision mode, the displacement coefficients of the first points are set to 0, that is, the displacements neighboring the base point (e.g., PB_1, PB_2, and PB_3) are inferred to be equal to 0, and are recursively applied to a previously reconstructed LOD, so that the redundancy problem of the displacement coefficients at higher LODs can be improved, the coded bits of the displacement coefficients can be saved, and the encoding and decoding efficiency can be improved.

[0382] In another embodiment of the present disclosure based on the same inventive concept as the foregoing embodiment, FIG. 32 is a schematic diagram of a component structure of a decoder provided in an embodiment of the present disclosure. As shown in FIG. 32, the decoder 320 may include a second determination unit 3201.

[0383] The second determining unit 3201 is configured to: decode the bitstream and determine a value of a first syntax element; determine a reconstructed mesh of a current LOD in the current mesh when the first syntax element indicates that the current mesh adopts a non-linear subdivision mode; subdivide the reconstructed mesh of the current LOD to determine a subdivided mesh of the current LOD; determine displacement coefficients of the first points of the current LOD as 0 when the current LOD is an i-th LOD;; determine a reconstructed mesh of a next LOD in the current mesh based on the subdivided mesh of the current LOD and the displacement coefficients of the first points of the current LOD. Here, i is an integer greater than 2, and the first points include vertices of a reconstructed base mesh corresponding to the current mesh.

[0384] It can be understood that in this embodiment, the "unit" may be a partial circuit, a partial processor, a partial program or software, etc., and of course may be a module, or may be non-modular. Moreover, the components in this embodiment may be integrated in one processing unit, various units may exist physically individually, or two or more units may be integrated in one unit. The integrated unit can be realized in the form of hardware or in the form of software function modules.

[0385] The integrated units may be stored in a computer-readable storage medium if implemented in the form of software functional modules and not sold or used as stand-alone products. Based on this understanding, the present embodiment provides a computer-readable storage medium, applied to a decoder 320, that stores a computer program that, when executed by a second processor, implements the method described in any of the preceding embodiments.

[0386] Based on the composition of the decoder 320 and the computer-readable storage medium, FIG. 33 is a schematic diagram of a specific hardware structure of a decoder provided in an embodiment of the present disclosure. As shown in FIG. 33, the decoder 320 may include a second communication interface 3301, a second memory 3302, and a second processor 3303. The components are coupled together via a second bus system 3304. It can be understood that the second bus system 3304 is used to implement connection communication between these components. The second bus system 3304 includes a power bus, a control bus, and a status signal bus in addition to a data bus. However, for the sake of clarity, the various buses are designated in FIG. 33 as the second bus system 3304.

[0387] The second communication interface 3301 is configured to receive and transmit signals in the process of transmitting and receiving information with other external network elements.

[0388] The second memory 3302 is configured to store computer programs capable of running on the second processor 3303.

[0389] The second processor 3303 is configured to perform operations of when running the computer program: decoding a bitstream to determine a value of a first syntax element; when the value of first syntax element indicates that a current mesh adopts a non-linear subdivision mode, determining a reconstructed mesh of a current LOD in the current mesh, and subdividing the reconstructed mesh of the current LOD to determine a subdivided mesh of the current LOD; determining displacement coefficients of first points of the current LOD as 0 when the current LOD is an i-th LOD, wherein i is an integer greater than 2, the first points include vertices of a reconstructed base mesh corresponding to the current mesh; and determining a reconstructed mesh of a next LOD in the current mesh according to the subdivided mesh of the current LOD and the displacement coefficients of the first points of the current LOD.

[0390] Optionally, as another embodiment, the second processor 3303 is further configured to execute the method described in any of the preceding embodiments when running the computer program.

[0391] It can be understood that the hardware functions of the second memory 3302 are similar to those of the first memory 3102, and the hardware functions of the second processor 3303 are similar to those of the first processor 3103; I won't go into details here.

[0392] The present embodiment provides a decoder. In the decoder, the displacement coefficients of first points are set to 0 when it is determined that the current mesh adopts a non-linear subdivision method, that is, the displacements neighboring the base point (e.g. PB_1, PB_2, and PB_3) are inferred to be equal to 0, and are recursively applied to the previously reconstructed LOD, so that the redundancy problem of the displacement coefficients at higher LODs can be improved, the coded bits of the displacement coefficient can be saved, and the encoding and decoding efficiency can be improved.

[0393] In yet another embodiment of the present disclosure, FIG. 34 is a schematic diagram of an integral structure of a codec system provided in an embodiment of the present disclosure. As shown in FIG. 34, the codec system 340 may include an encoder 3401 and a decoder 3402.

[0394] In embodiments of the present disclosure, encoder 3401 may be an encoder of any of the preceding embodiments, and decoder 3402 may be a decoder of any of the preceding embodiments.

[0395] It is to be noted that, in embodiments of the present disclosure, the terms "include", "include" or any other variation thereof are intended to cover non-exclusive inclusion, such that a process, method, article or device including a set of elements includes not only those elements, but also other elements not explicitly listed, or elements inherent in such a process, method, article or device. Without further limitation, an element qualified by the phrase "includes a..." does not exclude the existence of another identical element in the process, method, article or device in which it is included.

[0396] It is also to be noted that embodiments of the present disclosure also provide a computer program product including a computer program or instruction.

[0397] In some embodiments, the computer program product may be applied to the terminal device in an embodiment of the present disclosure, and the computer program or instruction causes the computer to execute the corresponding flow implemented by the terminal device in the various methods of the embodiment of the present disclosure, which will not be repeated here for the sake of brevity.

[0398] It is also to be noted that embodiments of the present disclosure also provide a computer program.

[0399] In some embodiments, the computer program can be applied to the terminal device in an embodiment of the present disclosure, and when the computer program is run on the computer, the computer is caused to execute the corresponding flow implemented by the terminal device in the various methods of the embodiment of the present disclosure. For the sake of brevity, it will not be repeated here.

[0400] Those of ordinary skill in the art will appreciate that the units and algorithmic steps of each example described in connection with the embodiments disclosed in the present disclosure can be implemented in electronic hardware or a combination of computer software and electronic hardware. Whether these functions are performed in hardware or software depends on the specific application and design constraints of the technical solution. A skilled person may implement the described functionality using different methods for each particular application, but such an implementation should not be considered outside the scope of the present disclosure.

[0401] Those skilled in the art can clearly understand that for the convenience and brevity of the description, the specific working process of the apparatus and unit described above can be referred to the corresponding process in the aforementioned method embodiment, and will not be described here in detail.

[0402] The above embodiments of the present disclosure are numbered for description only and do not represent advantages or disadvantages of the embodiments.

[0403] The methods disclosed in several method embodiments provided in the present disclosure can be arbitrarily combined without conflict to obtain new method embodiments.

[0404] The features disclosed in several product embodiments provided in the present disclosure can be arbitrarily combined without conflict to obtain new product embodiments.

[0405] The features disclosed in several method or device embodiments provided in the present disclosure can be arbitrarily combined without conflict to obtain new method embodiments or device embodiments.

[0406] The above is only a specific implementation of the present disclosure, but the protection scope of the present disclosure is not limited thereto. Any skilled person familiar with the technical field can easily think of changes or substitutions within the technical scope disclosed in the present disclosure, and should be covered within the protection scope of the present disclosure. Therefore, the scope of protection of the present disclosure shall be subject to the scope of protection of the said claims.

INDUSTRIAL APPLICABILITY

[0407] Provided are an encoding and decoding method, a bitstream, an encoder, a decoder, a medium and a product. At a decoder side, the bitstream is decoded to determine a value of a first syntax element; when the first syntax element indicates that the current mesh adopts a nonlinear subdivision mode, reconstructed mesh of the current LOD in the current mesh is determined, the reconstructed mesh of the current LOD is subdivided to determine a subdivided mesh of the current LOD; the displacement coefficients of the first points of the current LOD are determined as 0 when the current LOD is the i-th LOD. Here, i is an integer greater than 2 and the first points include vertices of the reconstructed base mesh corresponding to the current mesh. Based on the subdivided mesh of the current LOD and the displacement coefficients of the first points of the current LOD, a reconstructed mesh of the next LOD in the current mesh is determined. At the encoder side, when a current mesh adopts a non-linear subdivision mode, a value of a first syntax element is determined, the first syntax element is written into a bitstream, a reconstructed mesh of the current LOD in the current mesh is determined, and the reconstructed mesh of the current LOD is subdivided to determine a subdivided mesh of the current LOD. The displacement coefficients of the first points of the current LOD are determined as 0 when the current LOD is the i-th LOD. Here, i is an integer greater than 2 and the first points include vertices of the reconstructed base mesh corresponding to the current mesh. According to the subdivided mesh of the current LOD and the displacement coefficients of the current LOD, a reconstructed mesh of the next LOD in the current mesh is determined. That is, in the embodiments of the present disclosure, by adding a first syntax element indicating that the current mesh adopts a non-linear subdivision method, the displacement coefficient neighboring the vertex in the base layer can be removed from the displacement list in the encoding stage, and the displacement coefficient neighboring the vertex in the base layer is inferred to be equal to 0 in the decoding stage. Therefore, in the subsequent process of recursively applying the displacement coefficients to the previously reconstructed LOD, the redundancy problem of the displacement coefficients at the higher LODs can be improved, the coded bits of the displacement coefficient can be saved, and the encoding and decoding efficiency can be improved.

CLAIMS

1. A decoding method applied to a decoder, the decoding method comprising:

decoding a bitstream to determine a value of a first syntax element;

when the value of first syntax element indicates that a current mesh adopts a non-linear subdivision mode, determining a reconstructed mesh of a current Level of Details (LOD) in the current mesh, and subdividing the reconstructed mesh of the current LOD to determine a subdivided mesh of the current LOD;

determining displacement coefficients of first points of the current LOD as 0 when the current LOD is an i-th LOD, wherein i is an integer greater than a preset value, and the first points comprise vertices of a reconstructed base mesh corresponding to the current mesh; and

determining a reconstructed mesh of a next LOD in the current mesh according to the subdivided mesh of the current LOD and the displacement coefficients of the first points of the current LOD.

2. The decoding method of claim 1, further comprising:

when the current LOD is an i-th LOD, decoding the bitstream to determine displacement coefficients of second points of the current LOD, wherein the second points are points of the reconstructed base mesh corresponding to the current mesh except the first points; and

determining a reconstructed mesh of the next LOD in the current mesh according to a subdivided mesh of the current LOD and displacement coefficients of second points of the current LOD.

3. The decoding method of claim 1, further comprising:

decoding the bitstream to determine displacement coefficients of the current LOD when the current LOD is a second LOD; and

determining a reconstructed mesh of a next LOD in the current mesh according to a subdivided mesh of the current LOD and displacement coefficients of the current LOD.

4. The decoding method according to any one of claims 1-3, further comprising:

decoding the bitstream to determine a reconstructed base mesh;

subdividing the reconstructed base mesh to determine an initial subdivided mesh;

decoding the bitstream to determine displacement coefficients of the initial subdivided mesh; and

determining a reconstructed mesh of a first LOD in the current mesh according to the initial subdivided mesh and the displacement coefficients of the initial subdivided mesh.

5. The decoding method of claim 4, further comprising:

after determining the reconstructed mesh of the first LOD in the current mesh, subdividing the reconstructed mesh of the first LOD to determine a subdivided mesh of the second LOD;

decoding the bitstream to determine displacement coefficients of the subdivided mesh of the second LOD;

determining a reconstructed mesh of a next LOD of the current mesh according to the subdivided mesh of the second LOD and the displacement coefficients of the subdivided mesh of the second LOD; and

continuing subdivision operation, until a reconstructed mesh of an L-th LOD in the current mesh is determined,

wherein a value of L is correlated with a number of subdivision iterations for the current mesh.

6. The decoding method of claim 5, further comprising:

when the value of the first syntax element indicates that the current mesh adopts a recursive subdivision mode, determining a reconstructed mesh of the current LOD in the current mesh, subdividing the reconstructed mesh of the current LOD to determine a subdivided mesh of the current LOD;

decoding the bitstream to determine displacement coefficients of the current LOD; and

determining a reconstructed mesh of a next LOD in the current mesh according to the subdivided mesh of the current LOD and the displacement coefficients of the current LOD.

7. The decoding method of claim 6, further comprising:

after determining the reconstructed mesh of the next LOD in the current mesh, taking the reconstructed mesh of the next LOD as the reconstructed mesh of the current LOD, returning to performing the step of subdividing the reconstructed mesh of the current LOD to determine the subdivided mesh of the current LOD until the reconstructed mesh of the L-th LOD in the current mesh is determined.

8. The decoding method of claim 7, further comprising:

decoding the bitstream to determine a value for a second syntax element; and

determining the number of subdivision iterations of the current mesh according to the value of the second syntax element.

9. The decoding method of any one of claims 6-8, wherein decoding the bitstream to determine the displacement coefficients of the current LOD comprises:

decoding the bitstream to determine decoded displacement coefficients of the current LOD; and

pre-processed the decoded displacement coefficients of the current LOD to determine the displacement coefficients of the current LOD.

10. The decoding method of claim 9, wherein pre-processed the decoded displacement coefficients of the current LOD to determine the displacement coefficients of the current LOD comprises:

determining quantization parameters of the current LOD;

determining inverse quantized displacement coefficients of the current LOD by inverse quantizing the decoded displacement coefficients of the current LOD according to the quantization parameters of the current LOD; and

performing inverse wavelet transform on the inverse quantized displacement coefficients of the current LOD to determine the displacement coefficients of the current LOD.

11. The decoding method of claim 10, wherein determining the quantization parameters of the current LOD comprises:

decoding the bitstream to determine the quantization parameters of the current LOD.

12. The decoding method of claim 10, wherein determining the quantization parameters of the current LOD comprises:

determining quantization parameters of a previous LOD of the current LOD;

decoding the bitstream to determine a quantization parameter increment of the current LOD; and

determining quantization parameters of the current LOD according to the quantization parameters of the previous LOD and the quantization parameter increment.

13. The decoding method of claim 9, wherein decoding the bitstream to determine decoded displacement coefficients of the current LOD comprises:

decoding the bitstream to determine a two-dimensional image; and

extracting the decoded displacement coefficients of the current LOD from the two-dimensional image according to a preset packing mode.

14. The decoding method of claim 13, further comprising:

decoding the bitstream to determine a value for a third syntax element; and

determining the preset packing mode according to the value of the third syntax element.

15. The decoding method of any one of claims 1-4, 5-8 and 10-14, wherein determining the reconstructed mesh of the next LOD in the current mesh according to the subdivided mesh of the current LOD and the displacement coefficients of the first points of the current LOD comprises:

performing a displacement operation on vertex coordinate information of the subdivided mesh of the current LOD according to the displacement coefficients to obtain the reconstructed mesh of the next LOD in the current mesh.

16. The decoding method of claim 6, further comprising:

when the first syntax element indicates that the current mesh adopts a midpoint subdivision mode, decoding the bitstream to determine a reconstructed base mesh;

subdividing the reconstructed base mesh to determine a subdivided mesh of at least one LOD in the current mesh;

decoding the bitstream to determine displacement coefficients of the at least one LOD in the current mesh; and

determining a reconstructed mesh of the at least one LOD in the current mesh according to the subdivided mesh of the at least one LOD in the current mesh and the displacement coefficients of the at least one LOD.

17. The decoding method of claim 16, wherein a number of the at least one LOD is correlated with the number of subdivision iterations of the current mesh.

18. The decoding method of claim 16, further comprising:

determining that the first syntax element indicates that the current mesh does not adopt a subdivision mode when the value of the first syntax element is a first value;

determining that the first syntax element indicates that the current mesh adopts a midpoint subdivision mode when the value of the first syntax element is a second value;

determining that the first syntax element indicates that the current mesh adopts a recursive subdivision mode when the value of the first syntax element is a third value; and

determining that the first syntax element indicates that the current mesh adopts a non-linear subdivision mode when the value of the first syntax element is a fourth value.

19. The decoding method of any one of claims 1-18, wherein the preset value is 2.

20. An encoding method applied to an encoder, the encoding method comprising:

when a current mesh adopts a nonlinear subdivision mode, determining a value of a first syntax element, writing the first syntax element into a bitstream, determining a reconstructed mesh of a current Level of Details (LOD) in the current mesh, and subdividing the reconstructed mesh of the current LOD to determine a subdivided mesh of the current LOD;

when the current LOD is an i-th LOD, determining displacement coefficients of first points of the current LOD as 0, wherein i is an integer greater than a preset value, and the first points comprise vertices of a reconstructed base mesh corresponding to the current mesh; and

determining a reconstructed mesh of a next LOD in the current mesh according to the subdivided mesh of the current LOD and the displacement coefficients of the first points of the current LOD.

21. The encoding method of claim 20, further comprising:

when the current LOD is an i-th LOD, determining displacement coefficients of second points of the current LOD, and writing the displacement coefficients of the second points into the bitstream, wherein the second points are points of the reconstructed base mesh corresponding to the current mesh except the first points; and

determining the reconstructed mesh of a next LOD in the current mesh according to the subdivided mesh of the current LOD and the displacement coefficients of the second points of the current LOD.

22. The encoding method of claim 20, further comprising:

when the current LOD is a second LOD, determining displacement coefficients of the current LOD and writing the displacement coefficients of the current LOD into the bitstream; and

determining the reconstructed mesh of a next LOD in the current mesh according to the subdivided mesh of the current LOD and the displacement coefficients of the current LOD.

23. The encoding method of any one of claims 20-22, further comprising:

determining a base mesh of the current mesh, and writing the base mesh into the bitstream;

performing encoding and decoding processing on the base mesh to determine a reconstructed base mesh;

subdividing the reconstructed base mesh to determine an initial subdivided mesh;

determining displacement coefficients of the initial subdivided mesh and writing the displacement coefficients of the initial subdivided mesh into the bitstream; and

determining a reconstructed mesh of a first LOD in the current mesh according to the initial subdivided mesh and the displacement coefficients of the initial subdivided mesh.

24. The encoding method of claim 23, wherein determining the base mesh of the current mesh comprises:

determining an original mesh of the current mesh; and

downsampling the original mesh to obtain the base mesh.

25. The encoding method of claim 24, wherein determining the displacement coefficients of the initial subdivided mesh comprises:

determining the displacement coefficients of the initial subdivided mesh according to vertex coordinate information of the initial subdivided mesh and vertex coordinate information of the original mesh.

26. The encoding method of claim 24 or 25, further comprising:

after determining the reconstructed mesh of the first LOD in the current mesh, subdividing the reconstructed mesh of the first LOD to determine a subdivided mesh of the second LOD;

determining displacement coefficients of the subdivided mesh of the second LOD and writing the displacement coefficients of the subdivided mesh of the second LOD into the bitstream;

determining a reconstructed mesh of a next LOD of the current mesh according to the subdivided mesh of the second LOD and the displacement coefficients of the subdivided mesh of the second LOD; and

continuing subdivision operation, until a reconstructed mesh of an L-th LOD in the current mesh is determined,

wherein a value of L is correlated with a number of subdivision iterations for the current mesh.

27. The encoding method of claim 26, further comprising:

when the current mesh adopts the recursive subdivision mode, determining the value of the first syntax element, writing the first syntax element into the bitstream, determining the reconstructed mesh of the current LOD in the current mesh, subdividing the reconstructed mesh of the current LOD to determine the subdivided mesh of the current LOD;

determining displacement coefficients of the current LOD and writing the displacement coefficients of the current LOD into the bitstream; and

determining the reconstructed mesh of the next LOD in the current mesh according to the subdivided mesh of the current LOD and the displacement coefficients of the current LOD.

28. The encoding method of claim 27, further comprising:

after determining the reconstructed mesh of the next LOD in the current mesh, taking the reconstructed mesh of the next LOD as the reconstructed mesh of the current LOD, returning to performing the step of subdividing the reconstructed mesh of the current LOD to determine the subdivided mesh of the current LOD until a reconstructed mesh of the L-th LOD in the current mesh.

29. The encoding method of claim 28, further comprising:

determining the number of subdivision iterations of the current mesh; and

determining a second syntax element according to the number of subdivision iterations of the current mesh, and writing the second syntax element written into the bitstream.

30. The encoding method of claim 27 wherein determining the displacement coefficients of the current LOD comprises:

determining the displacement coefficients of the current LOD according to vertex coordinate information of the subdivided mesh of the current LOD and vertex coordinate information of the original mesh.

31. The encoding method of any one of claims 27-30, further comprising:

preprocessing the displacement coefficients of the current LOD to determine quantized displacement coefficients of the current LOD; and

encoding the quantized displacement coefficients of the current LOD to obtain encoded bits, and writing the encoded bits into the bitstream.

32. The encoding method of claim 31, wherein preprocessing the displacement coefficients of the current LOD to determine the quantized displacement coefficients of the current LOD comprising:

performing wavelet transform on the displacement coefficients of the current LOD to determine wavelet transform coefficients of the current LOD; and

quantizing the wavelet transform coefficients of the current LOD to determine the quantized displacement coefficients of the current LOD.

33. The encoding method of claim 32, wherein quantizing the wavelet transform coefficients of the current LOD to determine the quantized displacement coefficients of the current LOD comprising:

determining quantization parameters of the current LOD; and

quantizing the wavelet transform coefficients of the current LOD according to the quantization parameters of the current LOD to determine the quantized displacement coefficients of the current LOD.

34. The encoding method of claim 33, further comprising:

encoding the quantization parameters of the current LOD to obtain encoded bits, and writing the encoded bits into the bitstream.

35. The encoding method of claim 33, further comprising:

determining quantization parameters of a previous LOD of the current LOD; and

determining a quantization parameter increment of the current LOD according to the quantization parameters of the previous LOD and the quantization parameters of the current LOD; and

encoding the quantization parameter increment of the current LOD to obtain encoded bits, and writing the encoded bits into the bitstream.

36. The encoding method of claim 31, further comprising:

determining quantized displacement coefficients of at least one LOD in the current mesh, wherein the at least one LOD comprises the current LOD;

packing the quantized displacement coefficients of the at least one LOD into a two-dimensional image according to a preset packing mode; and

encoding the two-dimensional image to obtain encoded bits, and writing the encoded bits into the bitstream.

37. The encoding method of claim 36, further comprising:

determining a value of a third syntax element according to the preset packing mode; and

encoding the value of the third syntax element to obtain encoded bits, and writing the encoded bits into the bitstream.

38. The encoding method of any one of claims 20-37, wherein determining the reconstructed mesh of the next LOD in the current mesh according to the subdivided mesh of the current LOD and the displacement coefficients of the current LOD comprises:

performing a displacement operation on vertex coordinate information of the subdivided mesh of the current LOD according to the displacement coefficients to obtain the reconstructed mesh of the next LOD in the current mesh.

39. The encoding method of any one of claims 20-38, further comprising:

determining that the value of the first syntax element is a first value when the current mesh does not adopt the subdivision mode;

determining that the value of the first syntax element is a second value when the current mesh adopts the midpoint subdivision mode;

determining that the value of the first syntax element is a third value when the current mesh adopts a recursive subdivision mode; and

determining that the value of the first syntax element is a fourth value when the current mesh adopts a non-linear subdivision mode.

40. The encoding method of claim 39, further comprising:

determining to reconstructed base mesh when the current mesh adopts a midpoint subdivision mode;

subdividing the reconstructed base mesh to determine a subdivided mesh of at least one LOD of the current mesh;

determining displacement coefficients of the at least one LOD in the current mesh; and

determining a reconstructed mesh of the at least one LOD in the current mesh according to the subdivided mesh of the at least one LOD in the current mesh and the displacement coefficients of the at least one LOD.

41. The encoding method of claim 40, wherein a number of the at least one LOD is correlated with the number of subdivision iterations of the current mesh.

42. The encoding method of any one of claims 20-41, wherein the preset value is 2.

43. A bitstream generated by bit encoding according to information to be encoded, wherein the information to be encoded comprises at least one of:

a base mesh of a current mesh, displacement coefficients of at least one Level of Details (LOD) of the current mesh, quantization parameters of the at least one LOD of the current mesh, a quantization parameter increment of the at least one LOD of the current mesh, a value of a first syntax element, a value of a second syntax element, and a value of a third syntax element.

44. An encoder, comprising:

a determining unit configured to:

when a current mesh adopts a nonlinear subdivision mode, determine a value of a first syntax element, write the first syntax element into a bitstream, determine a reconstructed mesh of a current Level of Details (LOD) in the current mesh, and subdivide the reconstructed mesh of the current LOD to determine a subdivided mesh of the current LOD;

when the current LOD is an i-th LOD, determine displacement coefficients of first points of the current LOD as 0, wherein i is an integer greater than a preset value, and the first points comprise vertices of a reconstructed base mesh corresponding to the current mesh; and

determine a reconstructed mesh of a next LOD in the current mesh according to the subdivided mesh of the current LOD and the displacement coefficients of the first points of the current LOD.

45. An encoder, comprising:

a memory for storing a computer program executable by a processor;

the processor for executing the encoding method according to any one of claims 20-42 when running the computer program.

46. A decoder, comprising:

a determining unit configured to:

decode a bitstream to determine a value of a first syntax element;

when the value of the first syntax element indicates that a current mesh adopts a non-linear subdivision mode, determine a reconstructed mesh of a current Level of Details (LOD) in the current mesh, and subdivide the reconstructed mesh of the current LOD to determine a subdivided mesh of the current LOD;

determine displacement coefficients of first points of the current LOD as 0 when the current LOD is an i-th LOD, wherein i is an integer greater than a preset value, the first points comprise vertices of a reconstructed base mesh corresponding to the current mesh; and

determine a reconstructed mesh of a next LOD in the current mesh according to the subdivided mesh of the current LOD and the displacement coefficients of the first points of the current LOD.

47. A decoder comprising:

a memory for storing a computer program executable by a processor;

the processor for executing the decoding method according to any one of claims 1-19 when running the computer program.

48. A computer-readable storage medium having stored thereon a computer program that when executed by at least one processor, implements the decoding method according to any one of claims 1-18 or the encoding method according to any one of claims 20-42.

49. A computer program product comprising a computer program or instruction, wherein the computer program or instruction, when executed by at least one processor, implements the decoding method according to any one of claims 1-19, or the encoding method according to any one of claims 20-42.

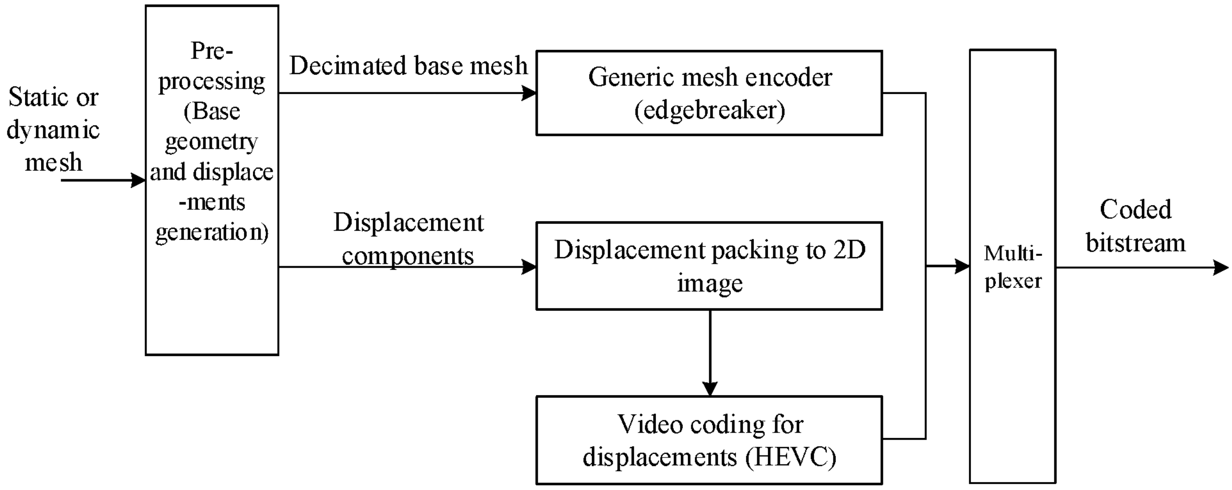

FIG. 1

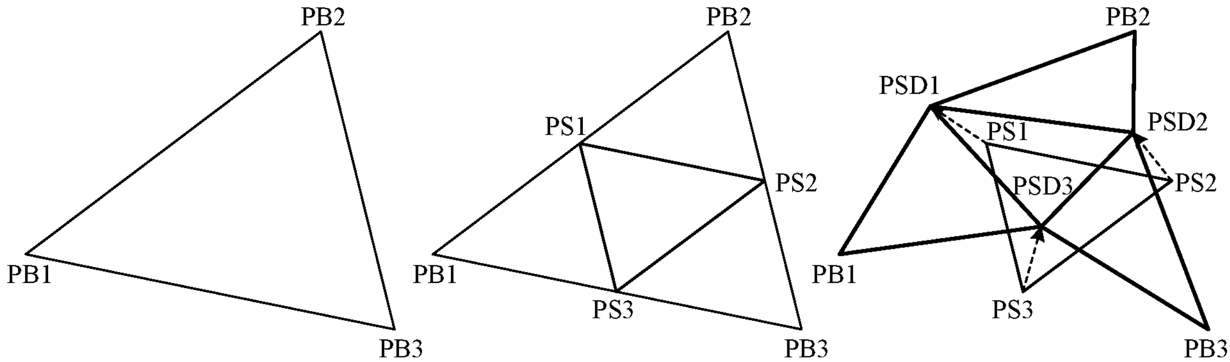

FIG. 2

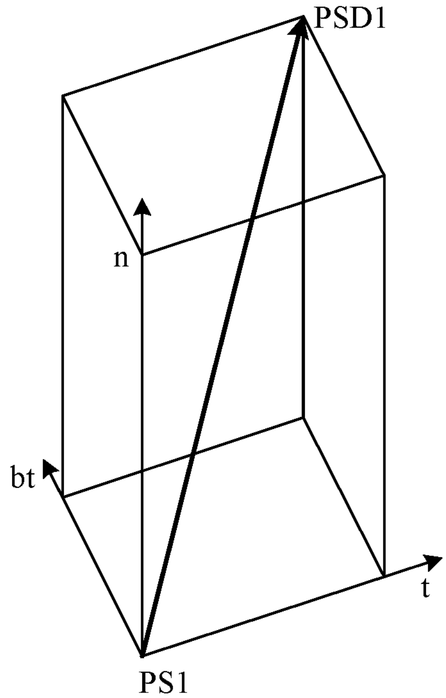

FIG. 3

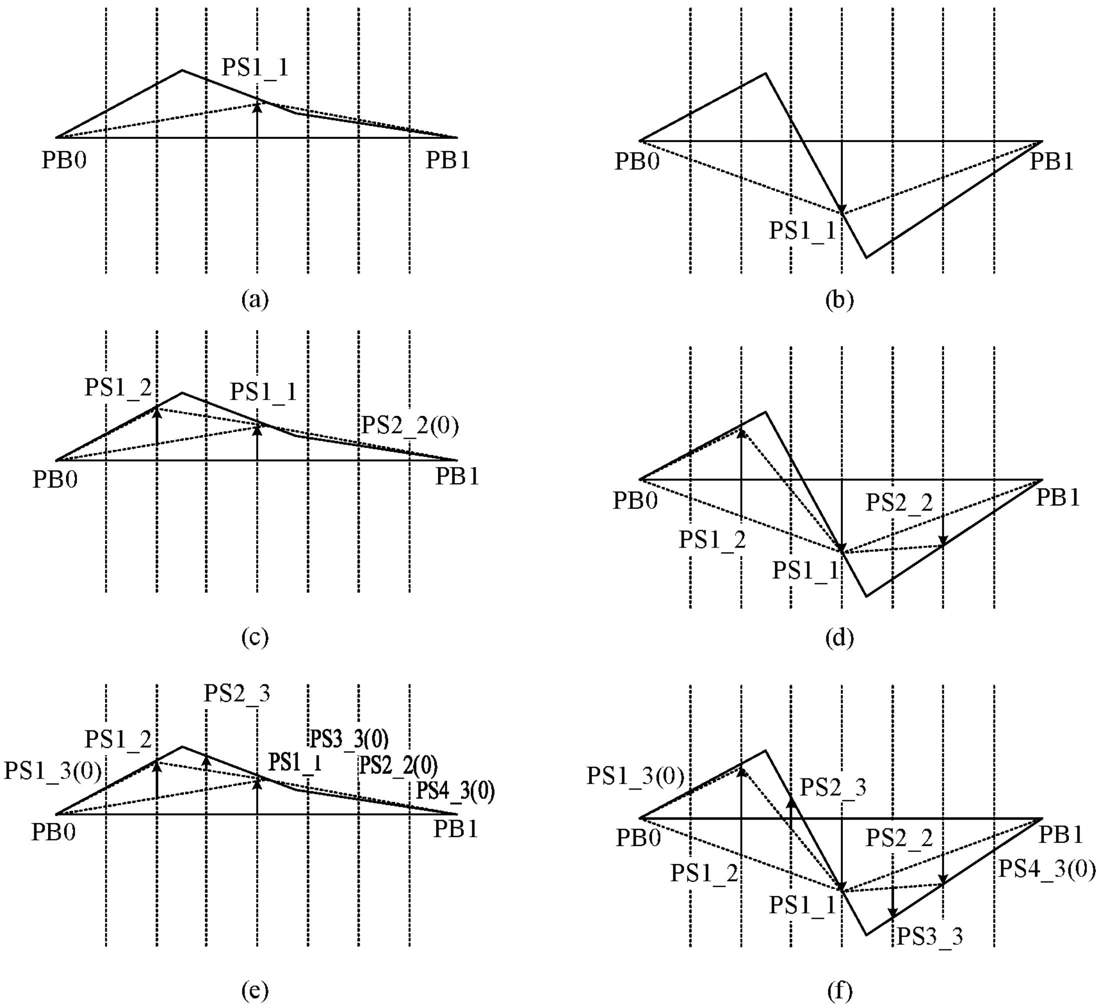
PS1_1
PB0
PB1
(a)
PB0
PB1
PS1_1
(b)
PS1_2
PS1_1
PS2_2(0)
PB0
PB1
(c)
PB0
PB1
PS2_2
PS1_2
PS1_1
(d)
PS2_3
PS1_2
PS3_3(0)
PS1_3(0)
PS1_1
PS2_2(0)
PS4_3(0)
PB0
PB1
(e)
PS1_3(0)
PS2_3
PB0
PB1
PS2_2
PS1_2
PS4_3(0)
PS1_1
PS3_3
(f)

FIG. 4

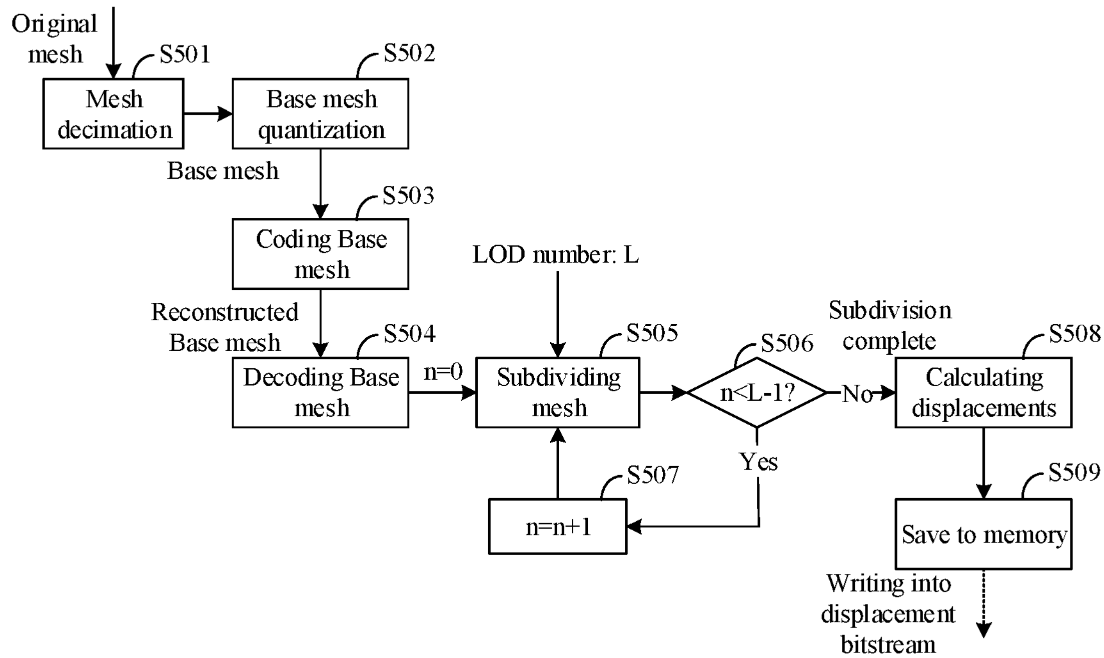
Original mesh
S501
Mesh decimation
S502
Base mesh quantization
Base mesh
S503
Coding Base mesh
LOD number: L
Reconstructed Base mesh
S504
Decoding Base mesh
n=0
S505
Subdividing mesh
S506
n<L-1?
Subdivision complete
No
S508
Calculating displacements
Yes
S507
n=n+1
S509
Save to memory
Writing into displacement bitstream

FIG. 5

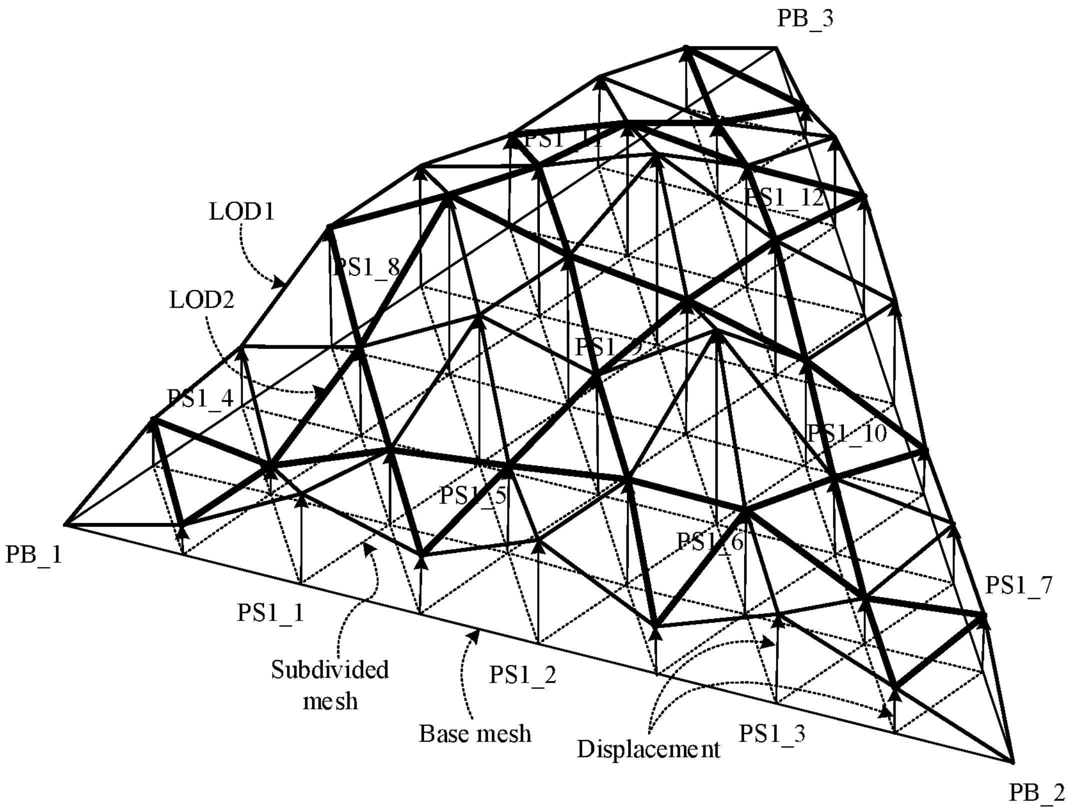
PB_3
LOD1
LOD2
PS1_11
PS1_12
PS1_8
PS1_9
PS1_4
PS1_10
PS1_5
PS1_6
PB_1
PS1_7
PS1_1
Subdivided mesh
PS1_2
Base mesh
Displacement
PS1_3
PB_2

FIG. 6

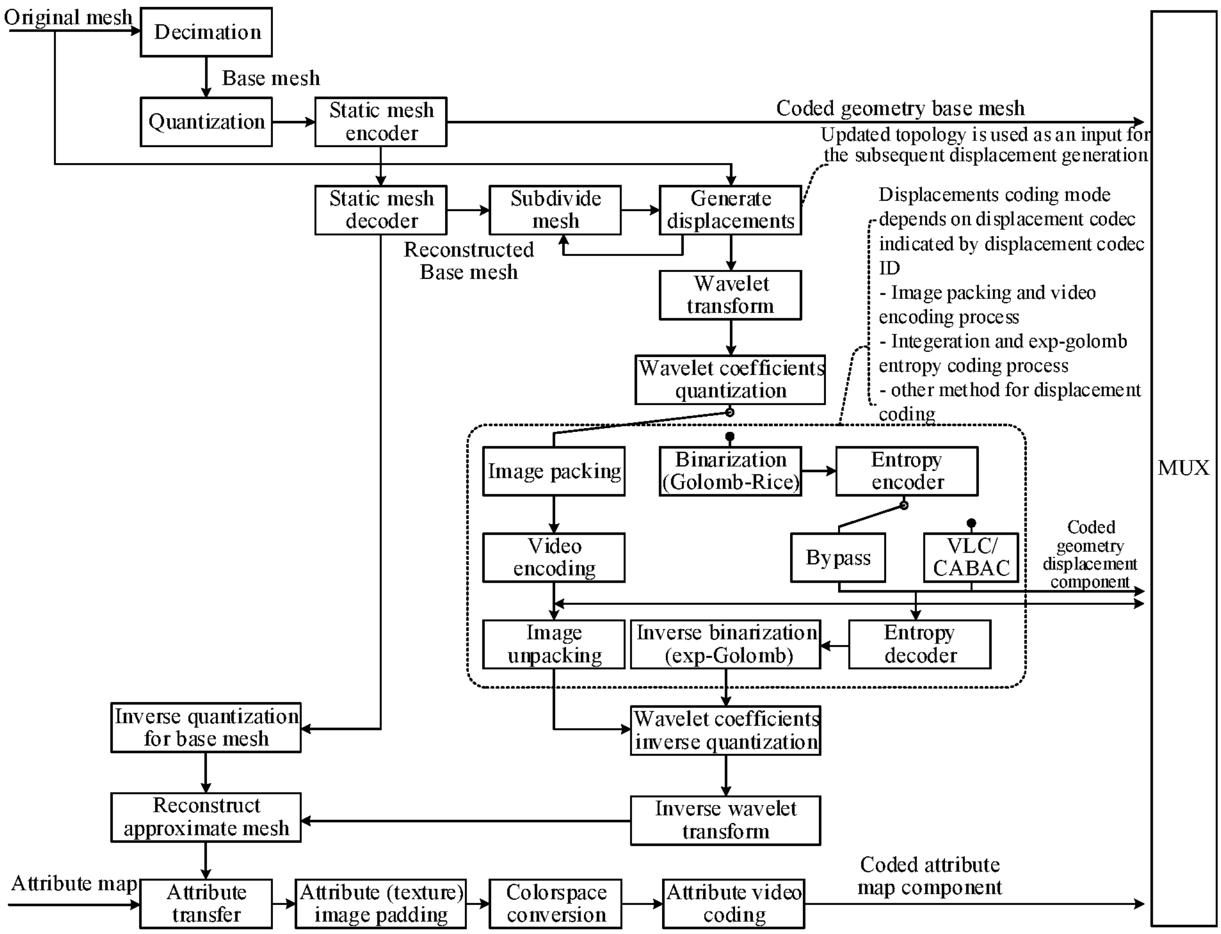
Original mesh
Decimation
Base mesh
Quantization
Static mesh encoder
Coded geometry base mesh
Updated topology is used as an input for the subsequent displacement generation
Static mesh decoder
Subdivide mesh
Generate displacements
Reconstructed Base mesh
Displacements coding mode depends on displacement codec indicated by displacement codec ID
- Image packing and video encoding process
- Integeration and exp-golomb entropy coding process
- other method for displacement coding
Wavelet transform
Wavelet coefficients quantization
Image packing
Binarization (Golomb-Rice)
Entropy encoder
Video encoding
Bypass
VLC/ CABAC
Coded geometry displacement component
Image unpacking
Inverse binarization (exp-Golomb)
Entropy decoder
MUX
Inverse quantization for base mesh
Wavelet coefficients inverse quantization
Reconstruct approximate mesh
Inverse wavelet transform
Attribute map
Attribute transfer
Attribute (texture) image padding
Colorspace conversion
Attribute video coding
Coded attribute map component

FIG. 7

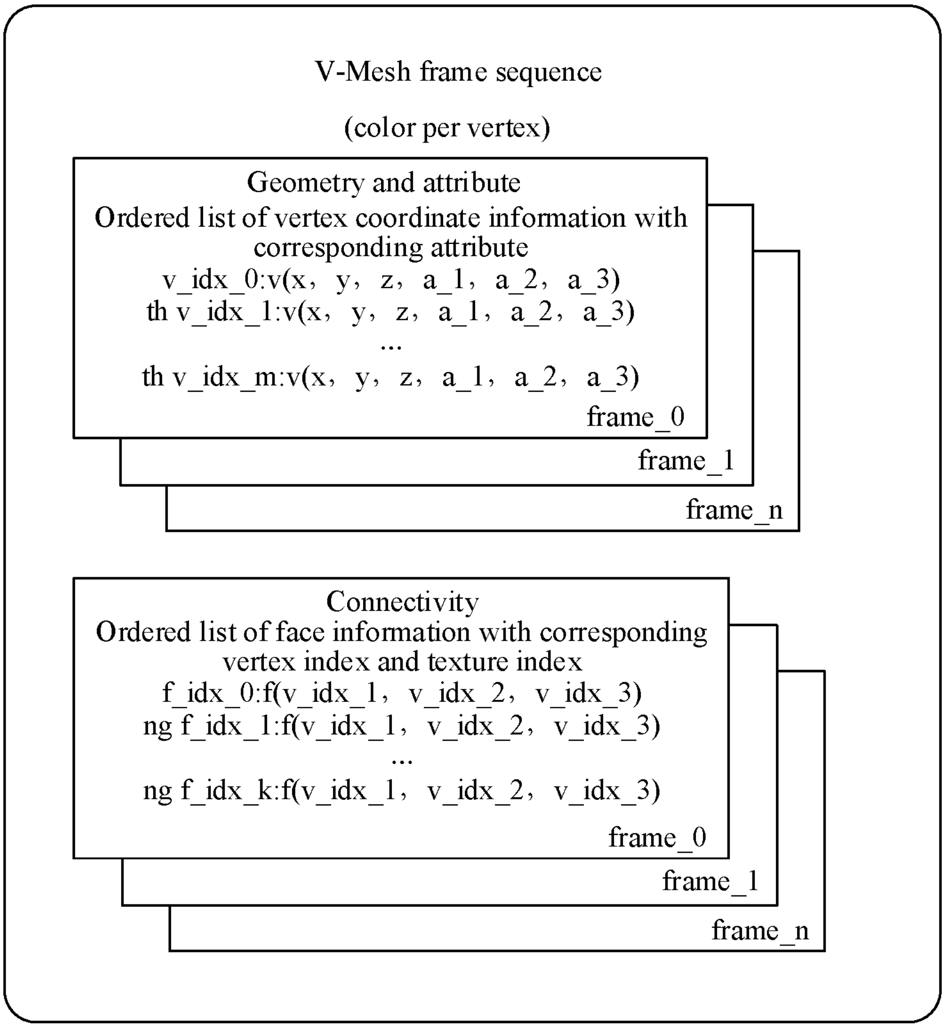
V-Mesh frame sequence
(color per vertex)
Geometry and attribute
Ordered list of vertex coordinate information with corresponding attribute
v_idx_0:v(x, y, z, a_1, a_2, a_3)
th v_idx_1:v(x, y, z, a_1, a_2, a_3)
...
th v_idx_m:v(x, y, z, a_1, a_2, a_3)
frame_0
frame_1
frame_n
Connectivity
Ordered list of face information with corresponding vertex index and texture index
f_idx_0:f(v_idx_1, v_idx_2, v_idx_3)
ng f_idx_1:f(v_idx_1, v_idx_2, v_idx_3)
...
ng f_idx_k:f(v_idx_1, v_idx_2, v_idx_3)
frame_0
frame_1
frame_n

FIG. 8

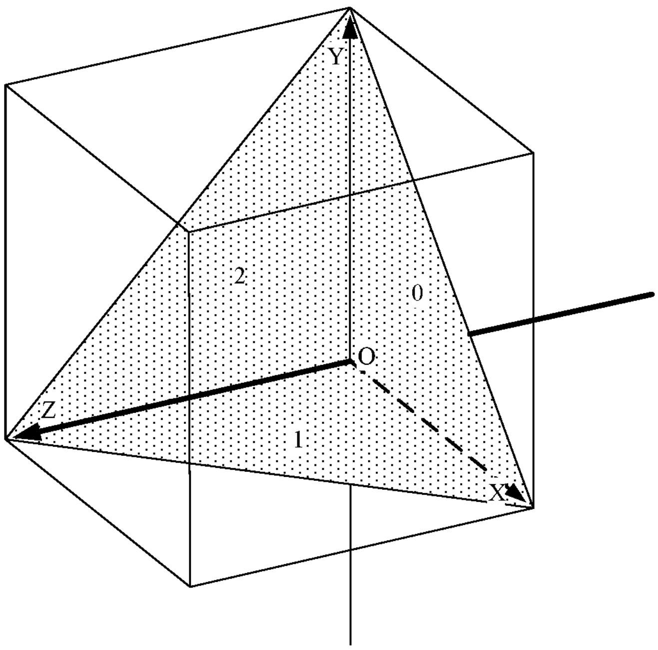
Y
2
0
O
Z
1
X

FIG. 9

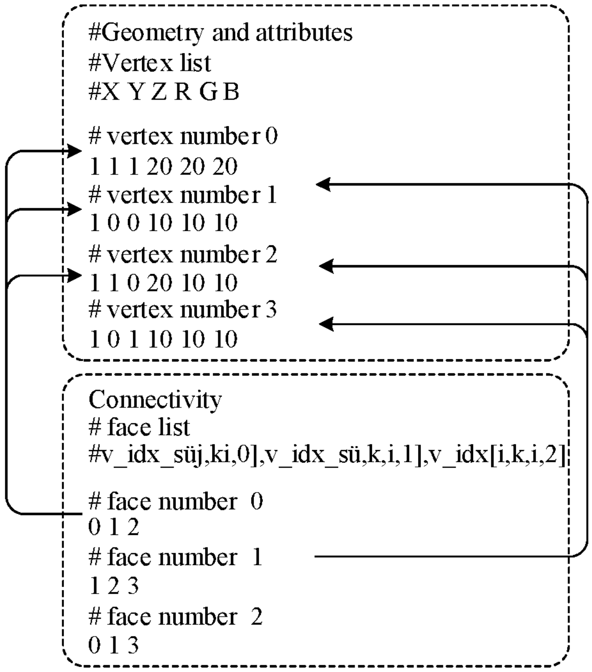
#Geometry and attributes
#Vertex list
#X Y Z R G B
vertex number 0
1 1 1 20 20 20
vertex number 1
1 0 0 10 10 10
vertex number 2
1 1 0 20 10 10
vertex number 3
1 0 1 10 10 10
Connectivity
face list
#v_idx_süj,ki,0],v_idx_sü,k,i,1],v_idx[i,k,i,2]
face number 0
0 1 2
face number 1
1 2 3
face number 2
0 1 3

FIG. 10

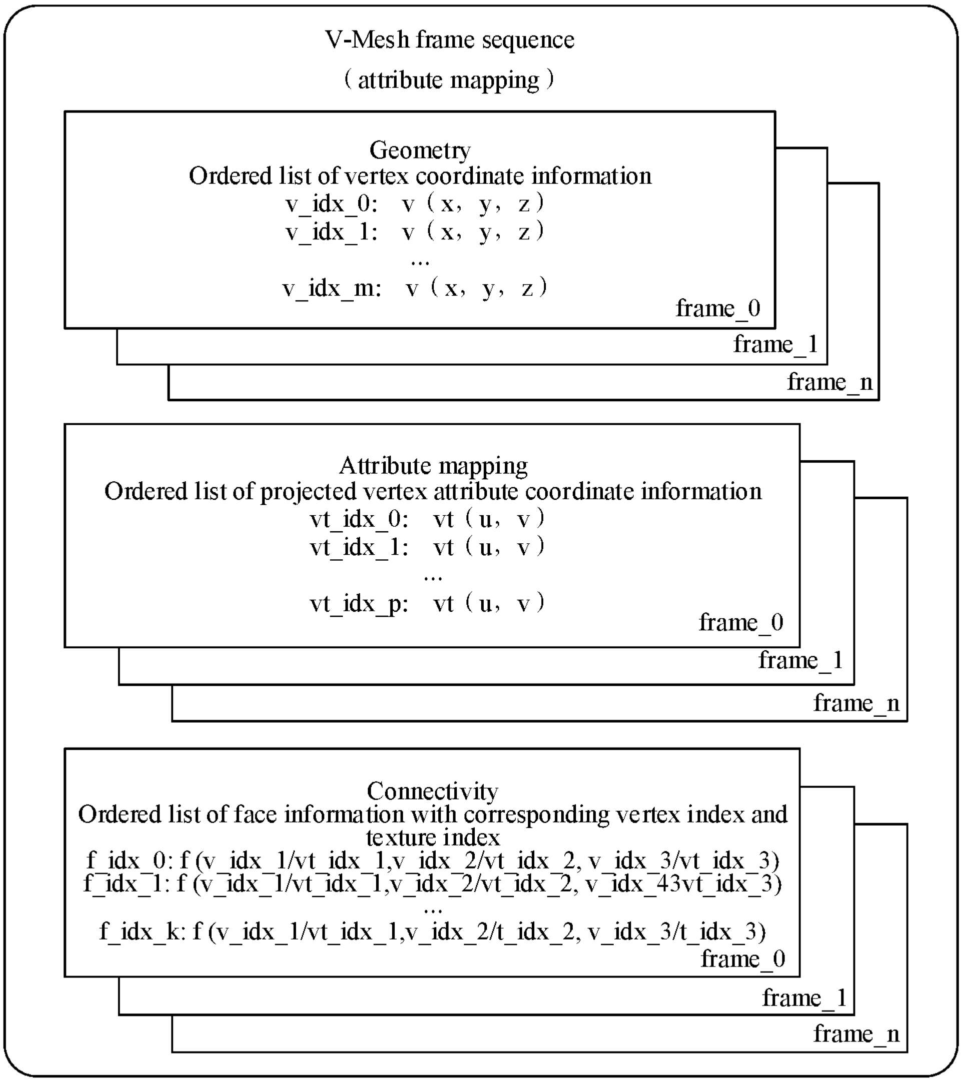
V-Mesh frame sequence
(attribute mapping)
Geometry
Ordered list of vertex coordinate information
v_idx_0: v（x，y，z）
v_idx_1: v（x，y，z）
...
v_idx_m: v（x，y，z）
frame_0
frame_1
frame_n
Attribute mapping
Ordered list of projected vertex attribute coordinate information
vt_idx_0: vt（u，v）
vt_idx_1: vt（u，v）
...
vt_idx_p: vt（u，v）
frame_0
frame_1
frame_n
Connectivity
Ordered list of face information with corresponding vertex index and texture index
f_idx_0: f (v_idx_1/vt_idx_1,v_idx_2/vt_idx_2, v_idx_3/vt_idx_3)
f_idx_1: f (v_idx_1/vt_idx_1,v_idx_2/vt_idx_2, v_idx_43vt_idx_3)
...
f_idx_k: f (v_idx_1/vt_idx_1,v_idx_2/t_idx_2, v_idx_3/t_idx_3)
frame_0
frame_1
frame_n

FIG. 11

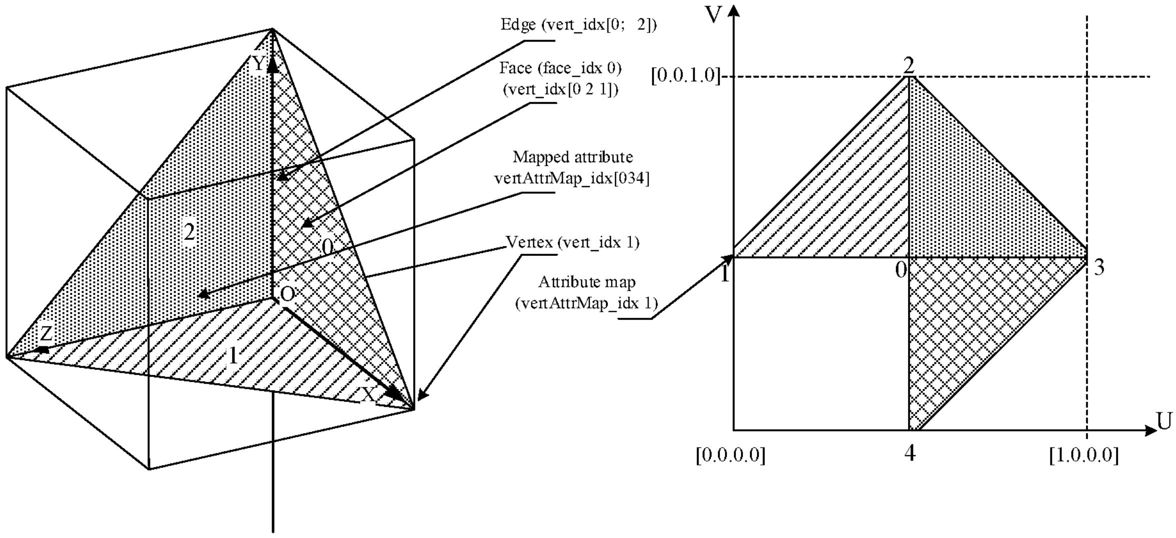

FIG. 12

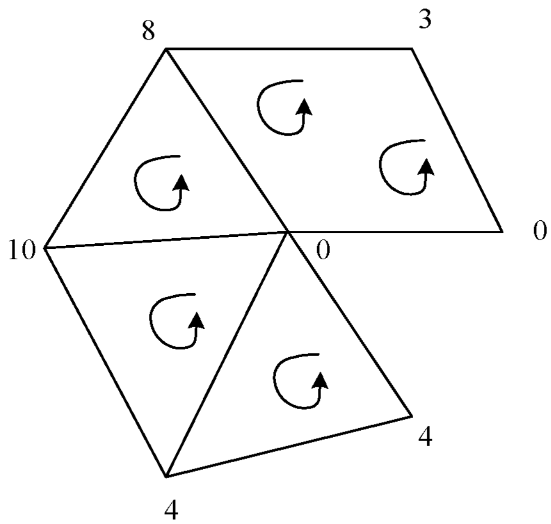

FIG. 13A

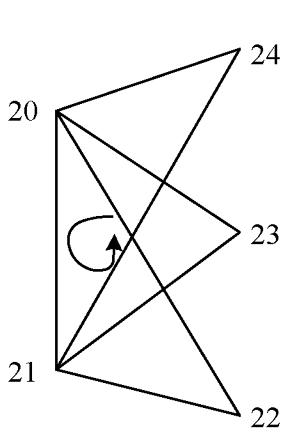

FIG. 13B

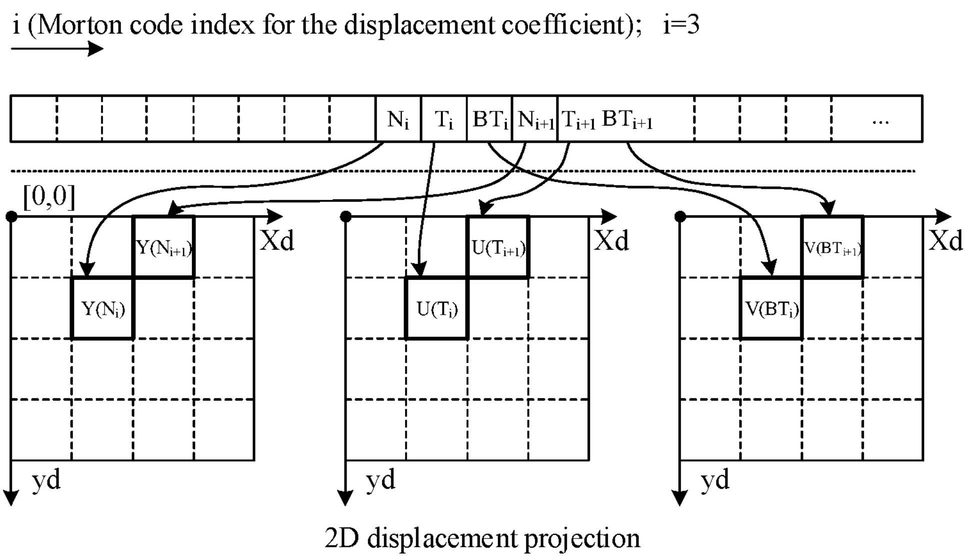

FIG. 14

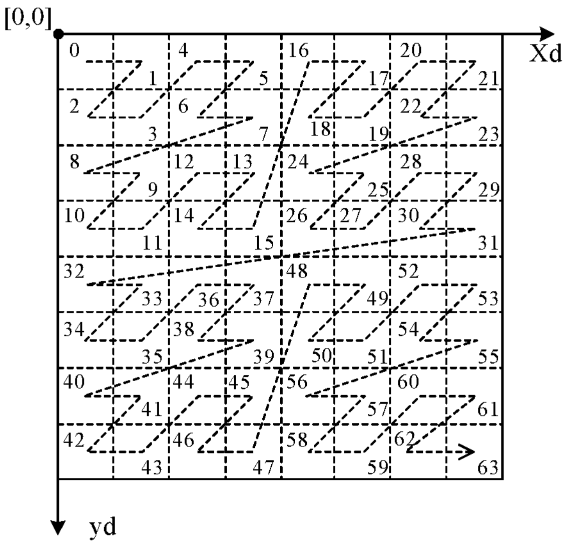

FIG. 15A

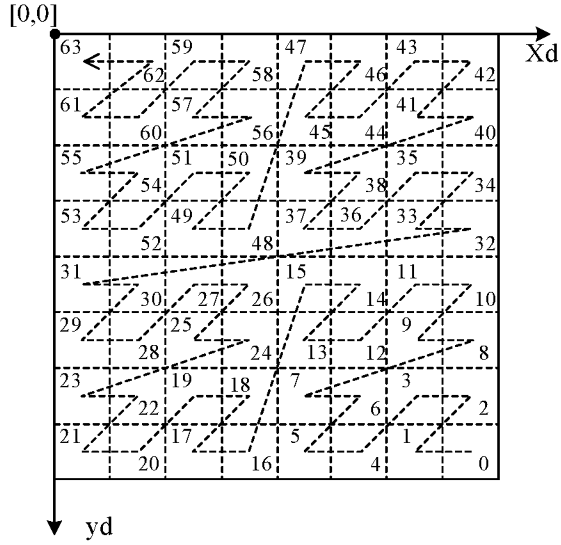

FIG. 15B

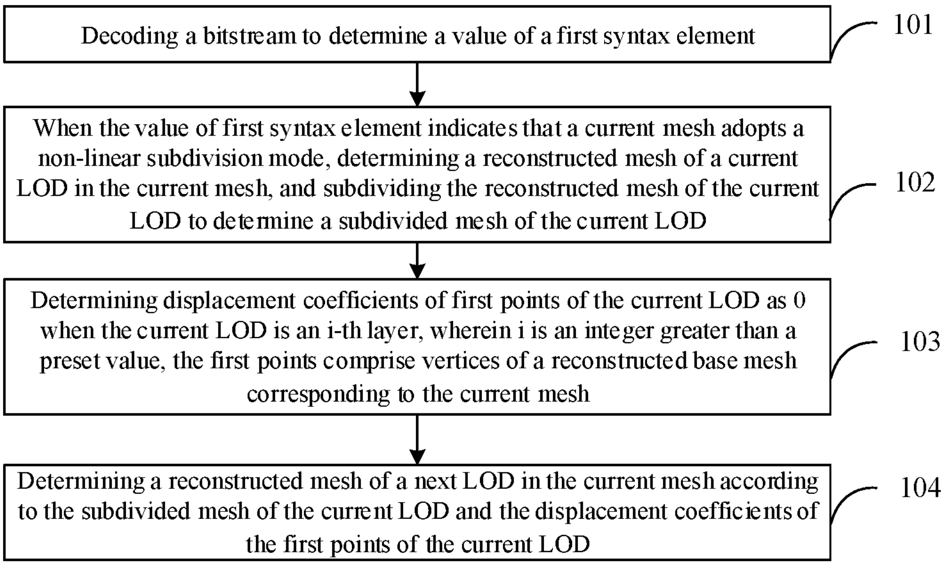

FIG. 16

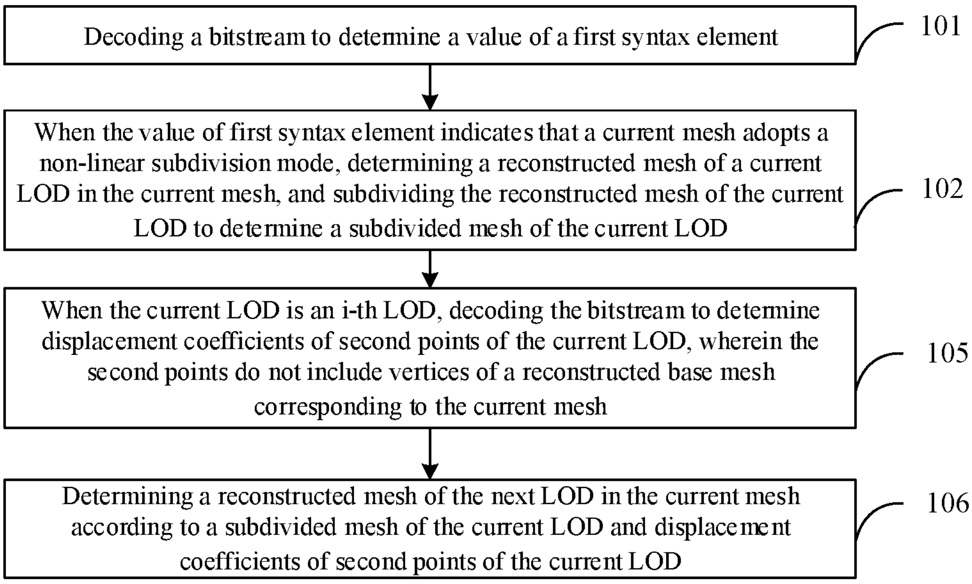

FIG. 17

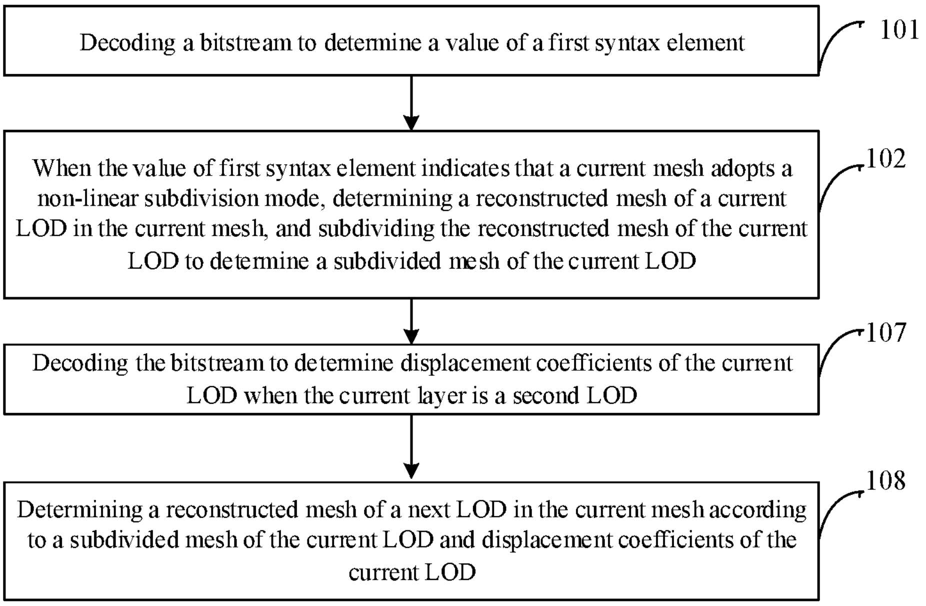

FIG. 18

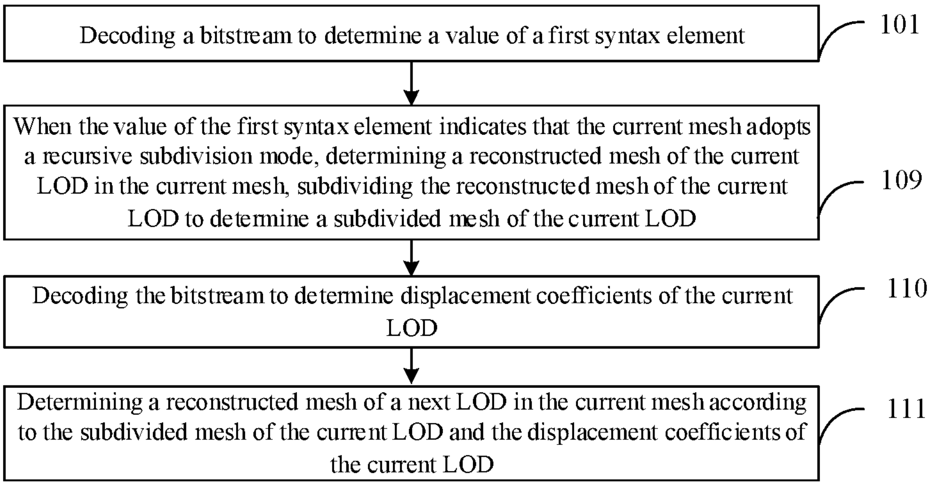

FIG. 19

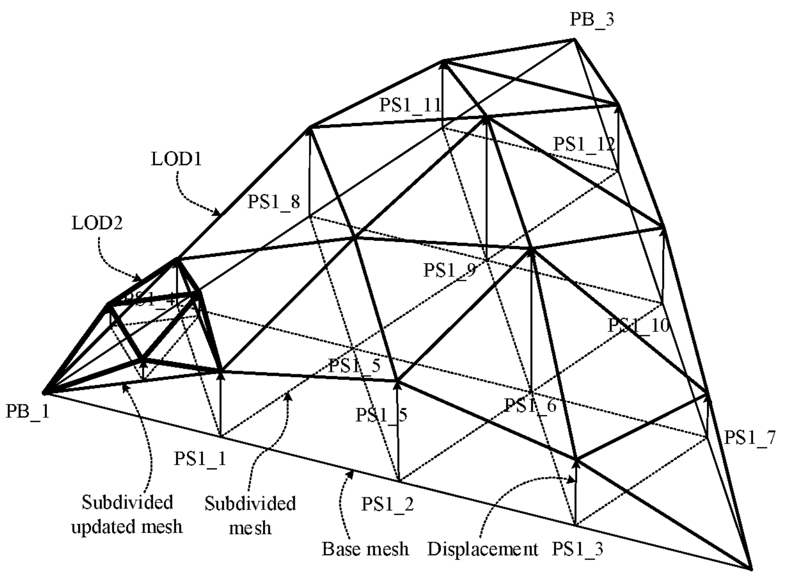

FIG. 20

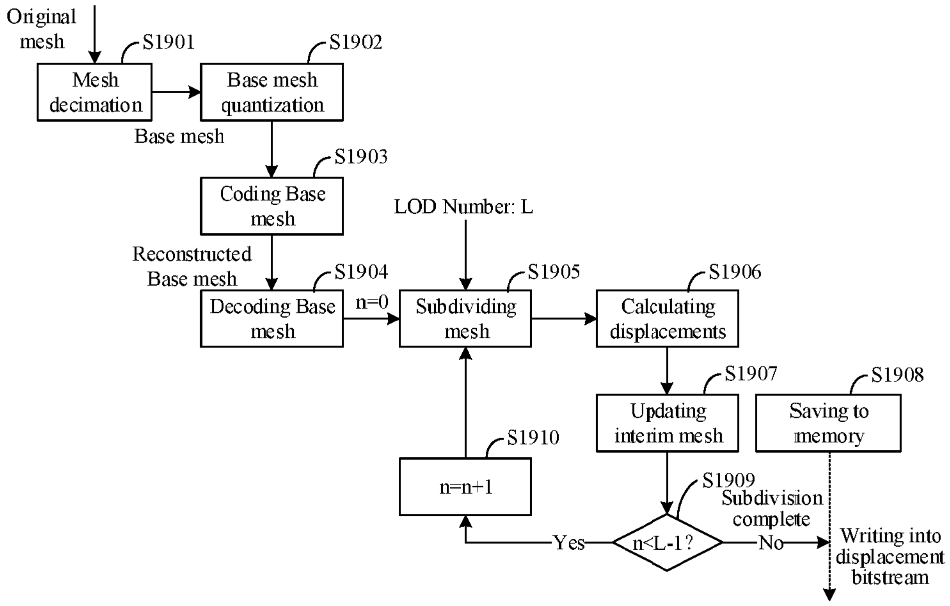
Original mesh
S1901
Mesh decimation
S1902
Base mesh quantization
Base mesh
S1903
Coding Base mesh
Reconstructed Base mesh
S1904
Decoding Base mesh
n=0
LOD Number: L
S1905
Subdividing mesh
S1906
Calculating displacements
S1907
Updating interim mesh
S1908
Saving to memory
S1910
n=n+1
S1909
Subdivision complete
Yes
n<L-1?
No
Writing into displacement bitstream

FIG. 21

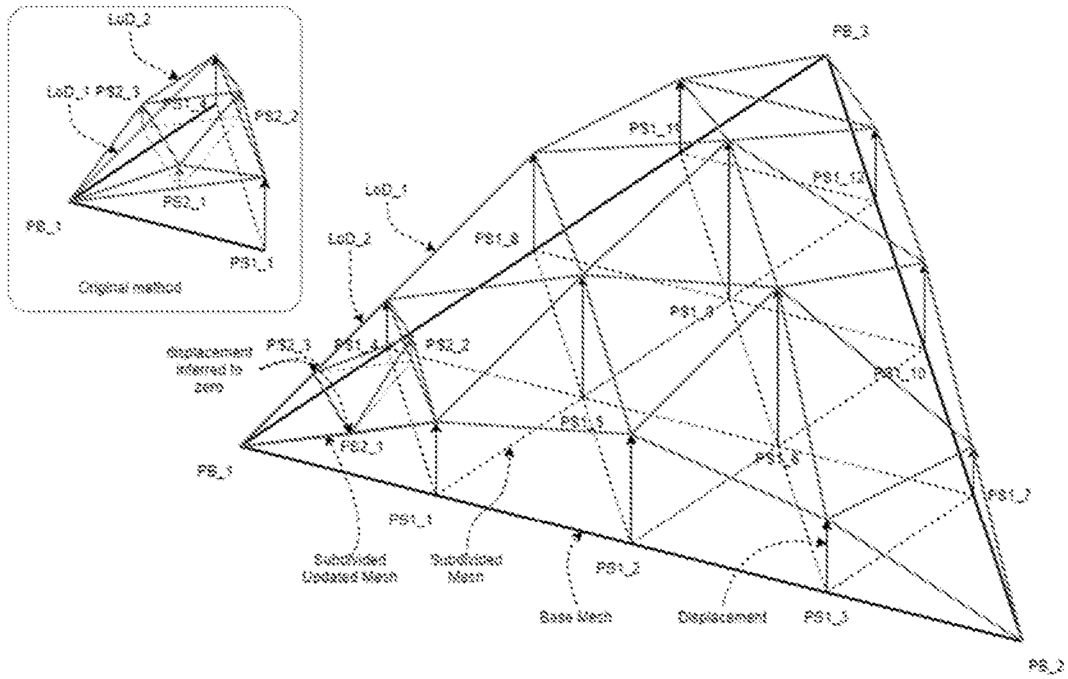
LoD_2
LoD_1
PS2_3
PS2_2
PS2_1
PS_1
PS1_1
Original method
PS_3
PS1_11
PS1_12
LoD_1
PS1_8
LoD_2
PS1_9
displacement inferred to zero
PS2_3
PS1_4
PS2_2
PS1_10
PS1_5
PS2_1
PS1_6
PS_1
PS1_7
PS1_1
Subdivided Updated Mesh
Subdivided Mesh
PS1_2
Base Mesh
Displacement
PS1_3
PS_2

FIG. 22

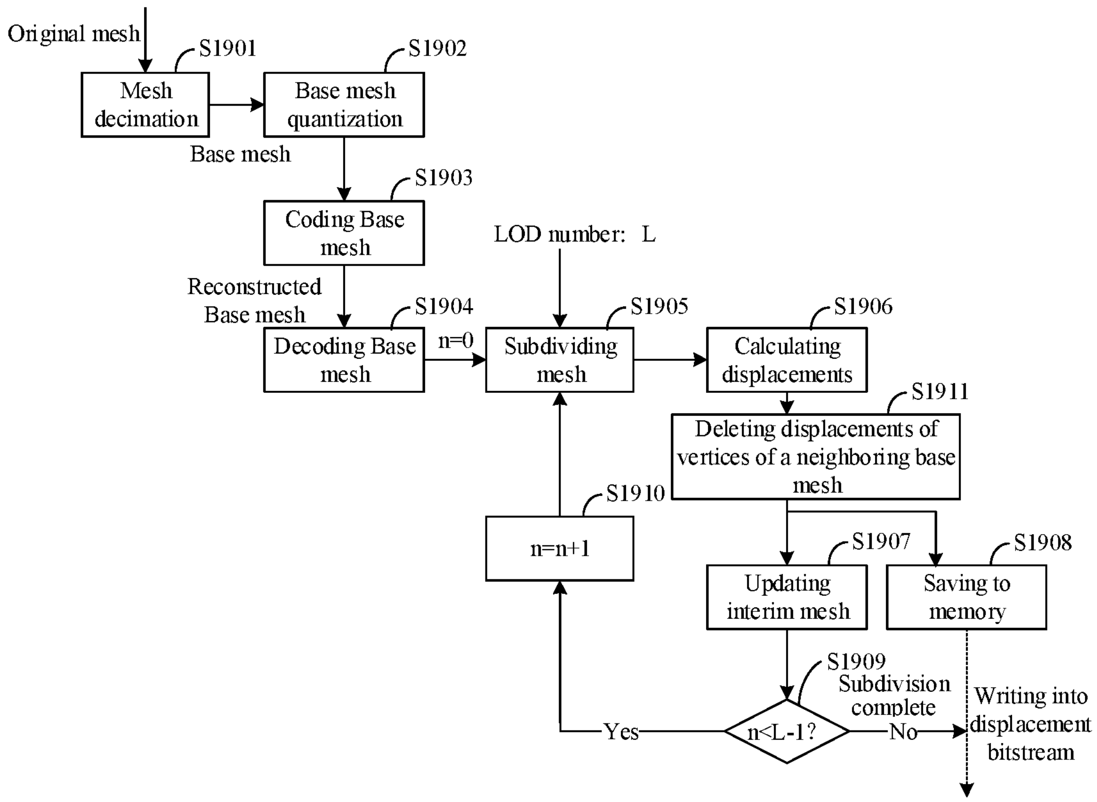
Original mesh
S1901
Mesh decimation
S1902
Base mesh quantization
Base mesh
S1903
Coding Base mesh
LOD number: L
Reconstructed Base mesh
S1904
Decoding Base mesh
n=0
S1905
Subdividing mesh
S1906
Calculating displacements
S1911
Deleting displacements of vertices of a neighboring base mesh
S1910
n=n+1
S1907
Updating interim mesh
S1908
Saving to memory
S1909
Subdivision complete
Yes
n<L-1?
No
Writing into displacement bitstream

FIG. 23

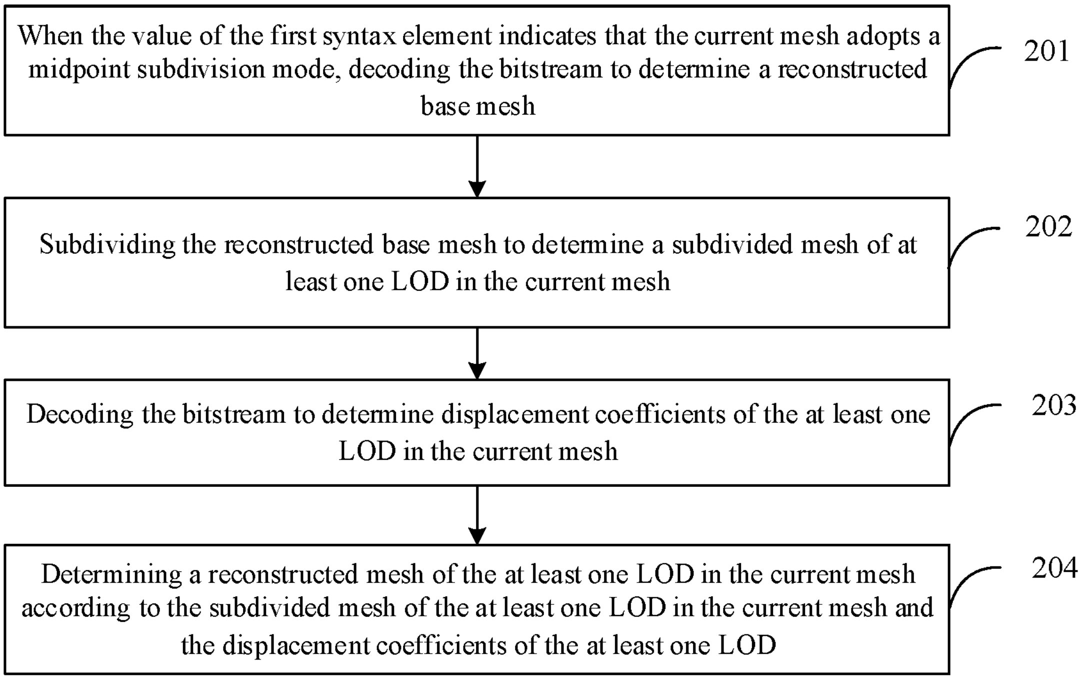
When the value of the first syntax element indicates that the current mesh adopts a midpoint subdivision mode, decoding the bitstream to determine a reconstructed base mesh
201
Subdividing the reconstructed base mesh to determine a subdivided mesh of at least one LOD in the current mesh
202
Decoding the bitstream to determine displacement coefficients of the at least one LOD in the current mesh
203
Determining a reconstructed mesh of the at least one LOD in the current mesh according to the subdivided mesh of the at least one LOD in the current mesh and the displacement coefficients of the at least one LOD
204

FIG. 24

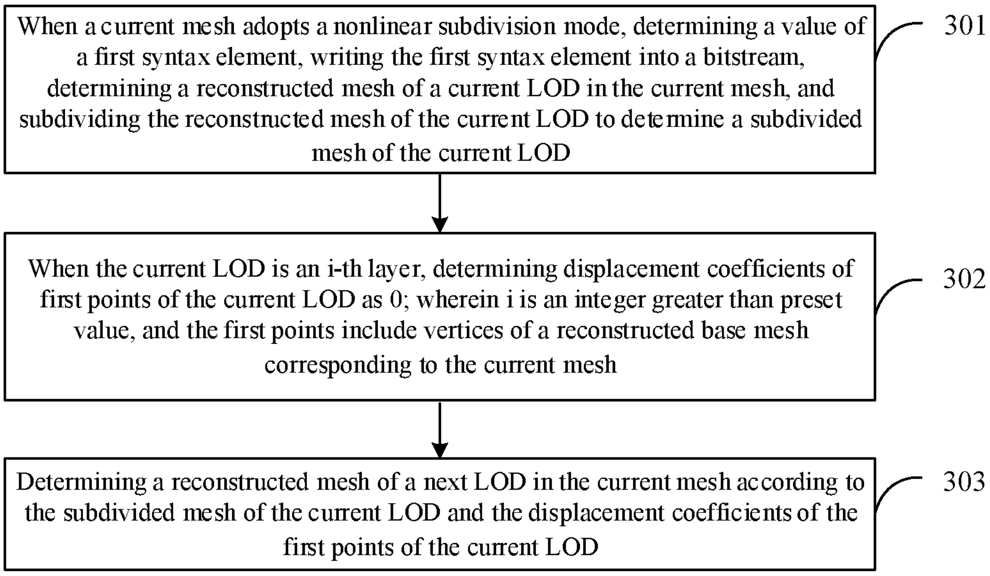

FIG. 25

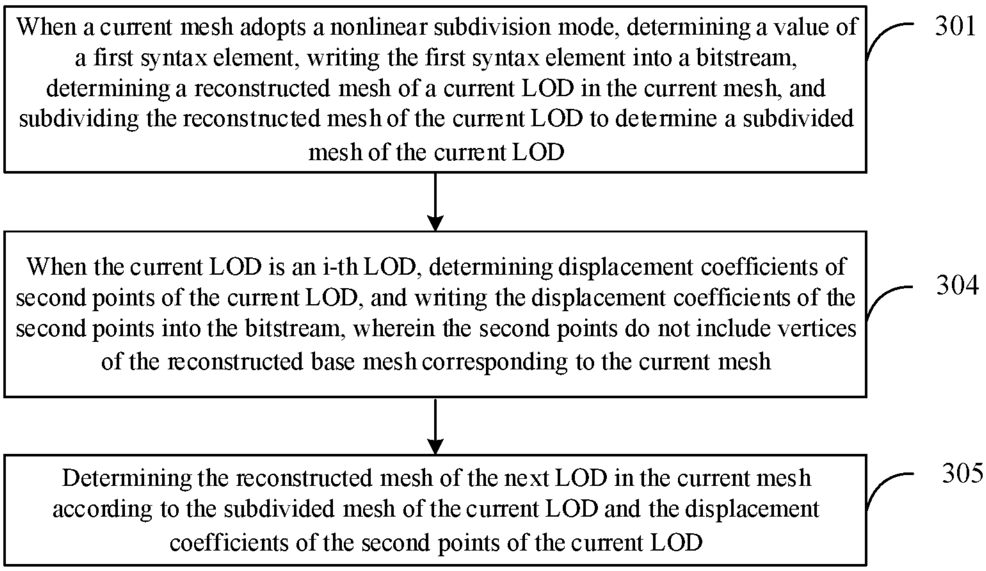

FIG. 26

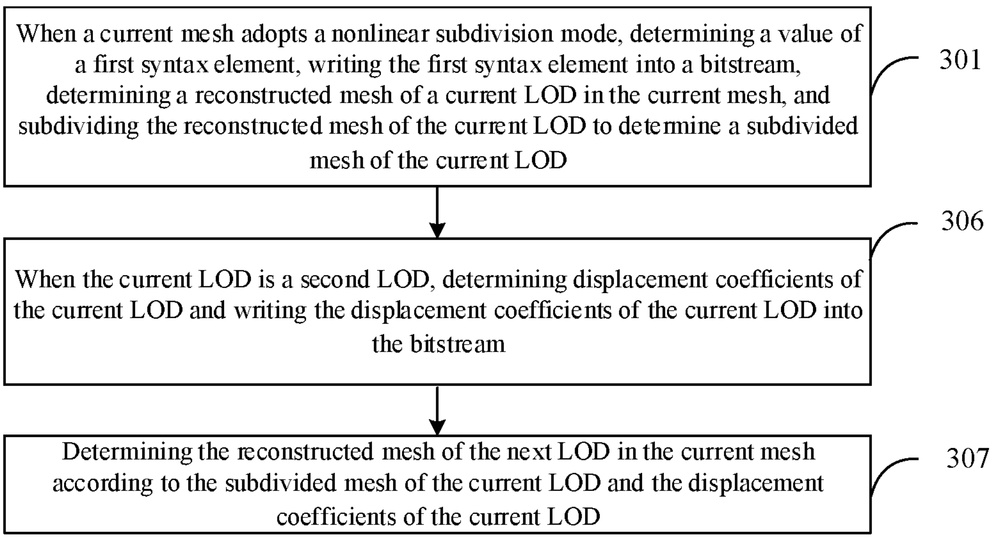

FIG. 27

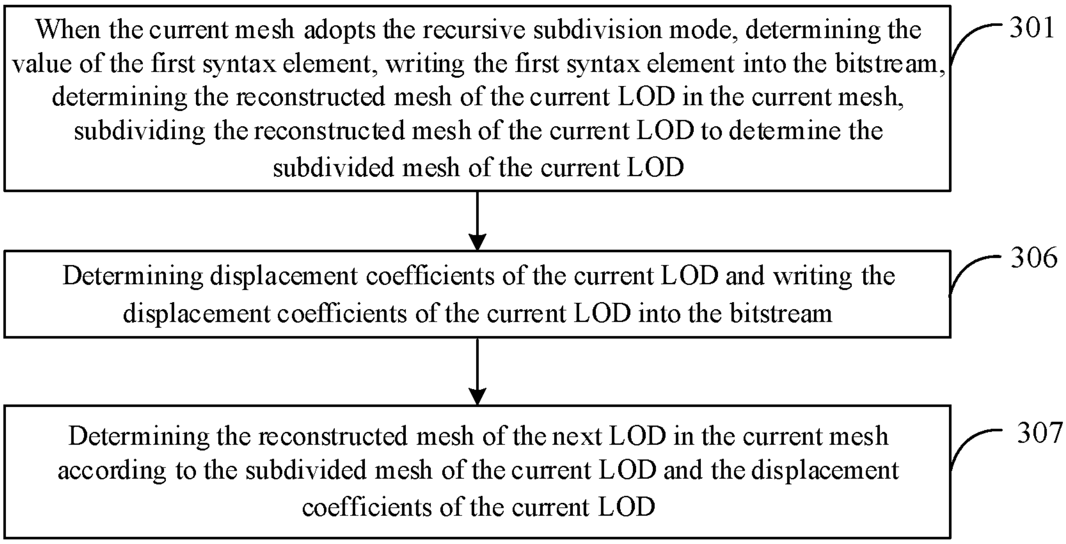

FIG. 28

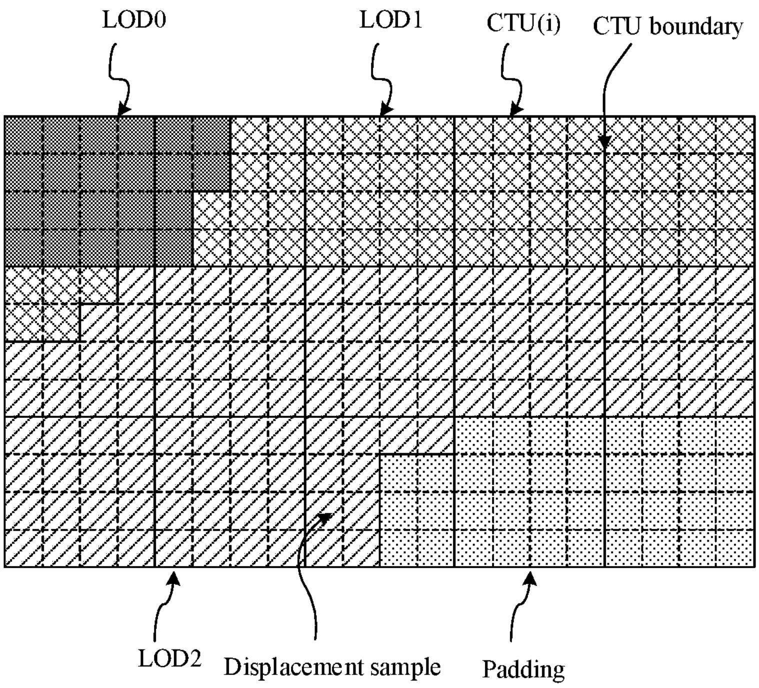

FIG. 29A

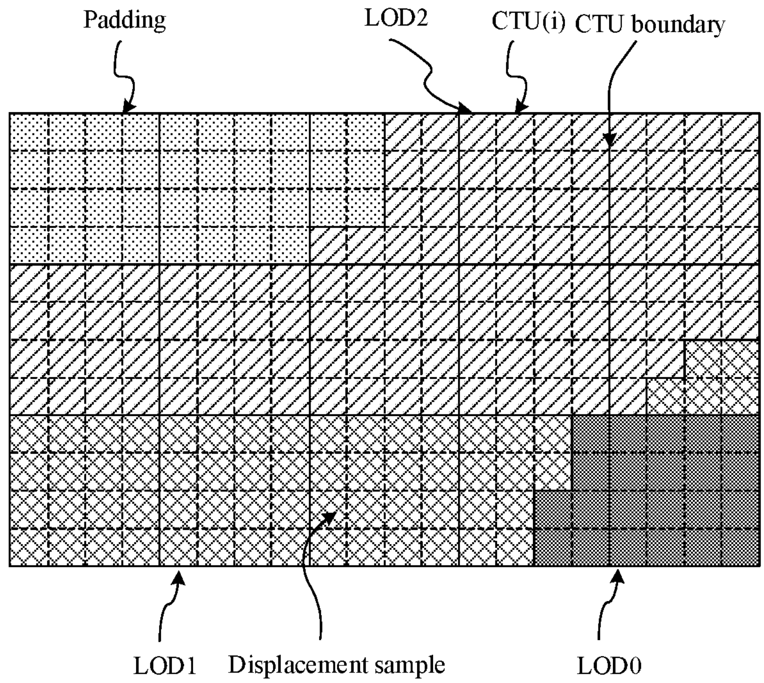

FIG. 29B

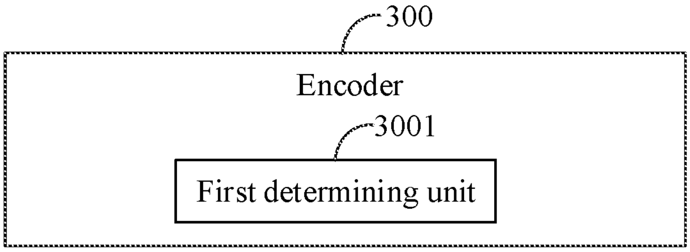

FIG. 30

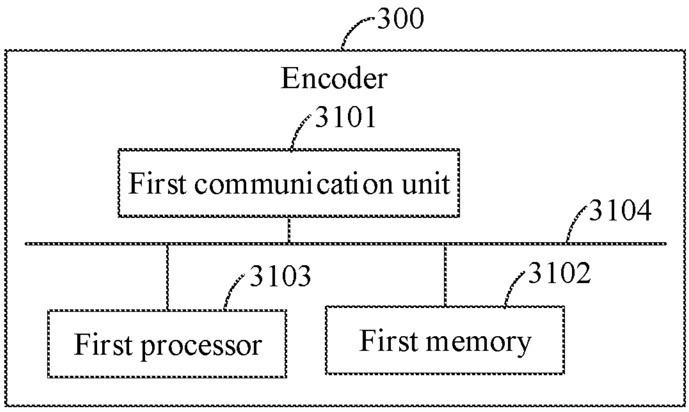

FIG. 31

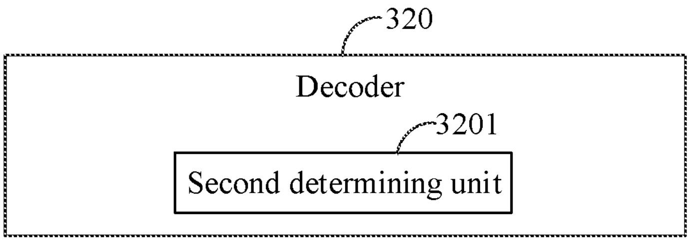

FIG. 32

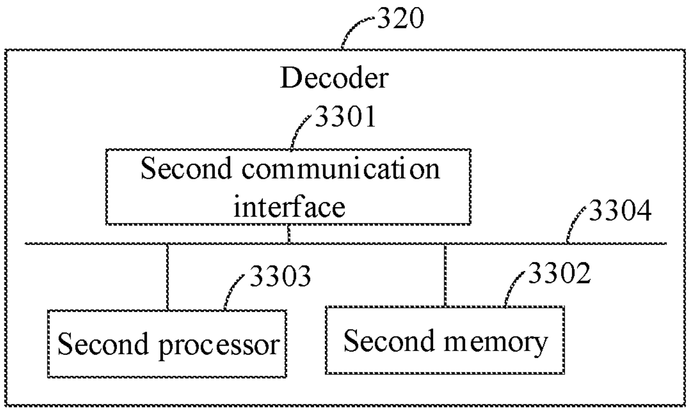
320
Decoder
3301
Second communication interface
3304
3303
3302
Second processor
Second memory

FIG. 33

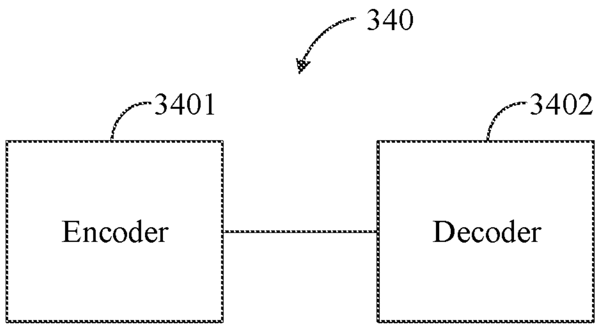
340
3401
3402
Encoder
Decoder

FIG. 34

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2024/099684

A. CLASSIFICATION OF SUBJECT MATTER

G06T9/00(2006.01)i; H04N19/597(2014.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC:H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

CNABS,VEN,CNTXT,ENTXT,ENTXTC:encode,compress,displacement,LOD,mesh,subdivision,sub-mesh,non-linear,coefficient,zero,determine,set,vertex,vertices

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2021287431 A1 (INTEL CORP) 16 September 2021 (2021-09-16) the description paragraphs 517-562, fig.63	43
A	CN 114331816 A (BEIJING DAJIA INTERNET INFORMATION TECHNOLOGY CO., LTD.) 12 April 2022 (2022-04-12) the whole document	1-49
A	CN 106408620 A (SIMUTECH INC.) 15 February 2017 (2017-02-15) the whole document	1-49
A	US 2021090301 A1 (APPLE INC) 25 March 2021 (2021-03-25) the whole document	1-49
A	WO 2008019262 A2 (QUALCOMM INC et al.) 14 February 2008 (2008-02-14) the whole document	1-49

☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:
- "A" document defining the general state of the art which is not considered to be of particular relevance
- "D" document cited by the applicant in the international application
- "E" earlier application or patent but published on or after the international filing date
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- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 September 2024	**19 September 2024**

Name and mailing address of the ISA/CN

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2024/099684

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US	2021287431	A1	16 September 2021	AU	2020294195	A1	30 September 2021
				SG	10202012215	RA	28 October 2021
				JP	2021149942	A	27 September 2021
				KR	20210116199	A	27 September 2021
				EP	3882859	A1	22 September 2021
				BR	102021001377	A2	28 September 2021
				TW	202137142	A	01 October 2021
CN	114331816	A	12 April 2022		None		
CN	106408620	A	15 February 2017		None		
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				US	2023030913	A1	02 February 2023
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				WO	2021062044	A1	01 April 2021
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				KR	20090047506	A	12 May 2009
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				TW	200830886	A	16 July 2008
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				WO	2008019262	A3	27 March 2008