

IMAGE PROCESSING METHOD AND APPARATUS, DEVICE, STORAGE MEDIUM, AND COMPUTER PROGRAM PRODUCT

TECHNICAL FIELD

[0001] This application relates, but is not limited, to the field of a computer vision technology, and in particular, to an image processing method and apparatus, a device, a storage medium, and a computer program product.

BACKGROUND

[0002] Relighting of an object is an important technology for achieving realistic rendering in movies and game industries. However, in the related art, fine scanning and modeling are usually performed on a to-be-relighted object by means of professionals and expensive professional devices, to achieve the relighting of the object, which is time-consuming and has high costs.

SUMMARY

[0003] In view of this, embodiments of this application provides at least an image processing method and apparatus, a device, a storage medium, and a computer program product.

[0004] The technical solutions of the embodiments of this application are implemented as follows.

[0005] In an aspect, an embodiment of this application provides an image processing method. The method includes the following operations.

[0006] An image frame sequence including a preset object and an object model corresponding to the preset object are acquired.

- [0007] A first geometric parameter and a first reflection parameter on a surface of the object model are determined based on the image frame sequence.
- [0008] The preset object in at least one first image frame in the image frame sequence is rendered based on a preset first lighting image, the first geometric parameter, and the first reflection parameter, to obtain at least one second image frame after relighting.
- [0009] In another aspect, an embodiment of this application provides an image processing apparatus. The apparatus includes an acquisition module, a determination module, and a rendering module.
- [0010] The acquisition module is configured to acquire an image frame sequence including a preset object and an object model corresponding to the preset object.
- [0011] The determination module is configured to determine a first geometric parameter and a first reflection parameter on a surface of the object model based on the image frame sequence.
- [0012] The rendering module is configured to render the preset object in at least one first image frame in the image frame sequence based on a preset first lighting image, the first geometric parameter, and the first reflection parameter, to obtain at least one second image frame after relighting.
- [0013] In yet another aspect, an embodiment of this application provides a computer device. The computer device includes a memory and a processor. The memory stores a computer program executable on the processor. The processor, when executing the computer program, implements part of all of steps in the above method.
- [0014] In still another aspect, an embodiment of this application provides a computer-readable storage medium. The computer-readable storage medium stores a computer program. Part or all of steps in the above method are implemented when the computer program is executed by a processor.
- [0015] In still another aspect, an embodiment of this application provides a computer program. The computer program includes a computer-readable code. When the

computer-readable code is operated in a computer device, a processor in the computer device executes and implements part or all of steps is the above method.

[0016] In still another aspect, an embodiment of this application provides a computer program product. The computer program product includes a non-transitory computer-readable storage medium storing a computer program. When the computer program is read and executed by a computer, part or all of steps in the above method are implemented.

[0017] In the embodiments of this application, the image frame sequence including a preset object and an object model corresponding to the preset object are acquired; the first geometric parameter and a first reflection parameter on a surface of the object model are determined based on the image frame sequence; and the preset object in at least one first image frame in the image frame sequence is rendered based on a preset first lighting image, the first geometric parameter, and the first reflection parameter, to obtain at least one second image frame after relighting. In this way, since the first geometric parameter and the first reflection parameter for relighting the preset object in at least first image frame in the image frame sequence are determined from the image frame sequence including the preset object, the first geometric parameter and the first reflection parameter for relighting the preset object may be determined based on the image frame sequence including preset objects of various postures, so that the preset objects of various postures can be relighted under a dynamic scenario. In addition, since the first geometric parameter and the first reflection parameter on the surface of the object model may accurately reflect a physical property of the object model, the accuracy of relighting can be enhanced, so that a more natural and realistic visual effect can be obtained. In addition, compared with the scheme in the related art of performing fine scanning and modeling on the preset object by means of professionals and expensive professional devices to achieve the relighting of the preset object, according to the embodiments of this application, the cost for relighting the preset object can be reduced, and the efficiency of relighting can be enhanced.

[0018] It should be understood that, the above general description and the following detailed description are merely exemplary and explanatory, and do not limit this

application.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] Drawings are incorporated into the specification and constitute a part of the specification. The drawings illustrate embodiments in accordance with this application and serve to describe the technical solutions of this application together with the specification.

[0020] FIG. 1 is a schematic implementation flowchart of an image processing method according to an embodiment of this application.

[0021] FIG. 2 is a schematic implementation flowchart of an image processing method according to an embodiment of this application.

[0022] FIG. 3A is a schematic implementation flowchart of an image processing method according to an embodiment of this application.

[0023] FIG. 3B is a schematic diagram of light at a contour point on a surface of an object model according to an embodiment of this application.

[0024] FIG. 4 is a schematic implementation flowchart of an image processing method according to an embodiment of this application.

[0025] FIG. 5 is a schematic implementation flowchart of an image processing method according to an embodiment of this application.

[0026] FIG. 6A is a schematic implementation flowchart of an image processing method according to an embodiment of this application.

[0027] FIG. 6B is a schematic diagram of an effect of relighting a human body by using an image processing method according to an embodiment of this application.

[0028] FIG. 7 is a schematic diagram of a composition structure of an image processing apparatus according to an embodiment of this application.

[0029] FIG. 8 is a schematic diagram of a hardware entity of a computer device according to an embodiment of this application.

DETAILED DESCRIPTION

[0030] For making the purposes, technical solutions and advantages of this application clearer, the technical solutions of this application will further be described below in combination with the drawings and embodiments in detail. The described embodiments should not be considered as limits to this application. All other embodiments obtained by those of ordinary skill in the art without creative work shall fall within the scope of protection of this application.

[0031] "Some embodiments" involved in the following descriptions describes a subset of all possible embodiments. However, it can be understood that "some embodiments" may be the same subset or different subsets of all the possible embodiments, and may be combined without conflicts.

[0032] Term "first/second/third" involved is only for distinguishing similar objects and does not represent a specific sequence of the objects. It can be understood that "first/second/third" may be interchanged to specific sequences or orders if allowed to implement the embodiments of this application described herein in sequences except the illustrated or described ones.

[0033] Unless otherwise defined, all technical and scientific terms in the specification have the same meaning as those skilled in the art, belonging to this application, usually understand. Terms used in the specification are only used for describing the purpose of this application, but not intended to limit this application.

[0034] In order to better understand an image processing method provided in an embodiment of this application, a solution in the related art of relighting an object is first described below.

[0035] Taking the relighting of a human body as an example, in the related art, the

scheme of relighting the human body may include: 1) A large-scale scanning device (light-stage) is used to collect mass data from each target human body, which is time-consuming and has high costs. 2) A two-dimensional human body weight lighting algorithm is used; the relighting of the human body in an original two-dimensional image is achieved by means of transfer learning or self-supervised learning from synthetic training data; and since a three-dimensional human body representation cannot be obtained, this scheme cannot realize the rendering of free postures and free views. 3) A three-dimensional neural rendering algorithm is used to perform human body modeling, to achieve relighting of the human body of free views. However, the three-dimensional neural rendering algorithm in the related art cannot correctly model a dynamic human body, thus realistic lighting and views cannot be rendered.

[0036] According to an image processing method provided in the embodiments of this application, the relighting of a preset object of various postures under a dynamic scenario may be realized, the cost of relighting the preset object can be reduced, and the accuracy and efficiency of relighting can be enhanced. The image processing method provided in the embodiments of this application may be performed by an electronic device. The electronic device may be various types of terminals such as a notebook computer, a tablet computer, a desktop computer, a set-top box, or a mobile device (for example, a mobile phone, a portable music player, a personal digital assistant, a special message device, and a portable game device), or may be implemented as a server. The server may be an independent physical server, may be a server cluster formed by a plurality of physical servers or a distributed system, or may be a cloud server configured to provide basic cloud computing services such as a cloud service, a cloud database, cloud computing, a cloud function, cloud storage, a network service, cloud communication, a middleware service, a domain name service, a security service, a Content Delivery Network (CDN), and a big data and artificial intelligence platform.

[0037] The technical solutions in the embodiments of this application are clearly and completely described below with reference to the drawings in the embodiments of this application.

[0038] FIG. 1 is a schematic implementation flowchart of an image processing

method according to an embodiment of this application. As shown in FIG. 1, the method includes the following S101 to S103.

[0039] At S101, an image frame sequence including a preset object and an object model corresponding to the preset object are acquired.

[0040] Herein, the preset object may be any proper object, and includes, but is not limited to, a human body, a vehicle, a cat, a dog, a tree, a house, and the like, and the embodiments of this application are not limited thereto.

[0041] The image frame sequence may include at least two first image frames. Each first image frame may include the preset object. During implementation, the at least one first image frame included in the image frame sequence may be at least one consecutive image frame in a video, or may be sampled from the video according to a set time step, and the embodiments of this application are not limited thereto.

[0042] The preset object included in each first image frame may have any proper postures. For example, in a case that the preset object is the human body, the preset object included in the first image frame may be at least one of a sideways human body, a tiptoe human body, a jumping human body, a bowed human body, or a rotating human body. For another example, in a case that the preset object is the cat, the preset object included in the first image frame may be at least one of a squatting cat, a cat lying on its stomach, a walking cat, or a jumping cat. During implementation, in the image frame sequence, postures of the preset objects in different first image frames may be same or different, which are not limited herein.

[0043] An object model corresponding to the preset object may be a three-dimensional model or a model of more than three dimensions, which is not limited herein. During implementation, the object model may be predetermined according to an actual preset object. In some implementations, the object model corresponding to the preset object may be determined according to an object type of the preset object actually included in the image frame sequence. For example, in the case that the preset object is the human body, the object model corresponding to the preset object may be a Skinned Multi-Person Linear (SMPL) model. In the case that the preset object is the cat, the object model

corresponding to the preset object may be a cat model. In a case that the preset object is a vehicle, the object model corresponding to the preset object may be a vehicle model.

[0044] At S102, a first geometric parameter and a first reflection parameter on a surface of the object model are determined based on the image frame sequence.

[0045] Herein, the first geometric parameter may be any proper parameter that can characterize the geometric property on the surface of the object model, and includes, but is not limited to, at least one of normal distribution or the light visibility of the surface of the object model.

[0046] Herein, the first reflection parameter may be any proper parameter that can characterize the light reflection property on the surface of the object model, and includes, but is not limited to, at least one of a diffuse reflection parameter (such as reflectance and reflection angle of diffuse reflection), or a specular reflection parameter (such as reflectance and reflection angle of specular reflection) of the surface of the object model.

[0047] In some implementations, the first geometric parameter on the surface of the object model includes the first geometric parameter of each contour point on the surface of the object model. The first reflection parameter on the surface of the object model includes the first reflection parameter of each contour point.

[0048] Since the image frame sequence includes the preset object, an appearance of the preset object is observed based on the image frame sequence. By aggregating appearance information of the preset object included in each first image frame in the image frame sequence, the geometric property and the light reflection property of a surface of the preset object may be determined. In this way, the first geometric parameter and the first reflection parameter on the surface of the object model corresponding to the preset object can be determined.

[0049] In some implementations, the first geometric parameter and the first reflection parameter on the surface of the object model may be determined from the image frame sequence by using a trained neural network. In some implementations, a pixel value and a color value of each pixel point corresponding to the preset object in each first image frame may be counted and analyzed, to determine the appearance information of the

preset object included in each first image frame, so as to determine the first geometric parameter and the first reflection parameter on the surface of the object model corresponding to the preset object. During implementation, those skilled in the art may adopt a proper manner to determine the first geometric parameter and the first reflection parameter on the surface of the object model according to actual situations, which are not limited herein.

[0050] At S103, the preset object in at least one first image frame in the image frame sequence is rendered based on a preset first lighting image, the first geometric parameter, and the first reflection parameter, to obtain at least one second image frame after relighting.

[0051] Herein, the first lighting image may be a lighting image that is predetermined according to an actual lighting scenario, and may reflect a lighting intensity of each direction under the lighting scenario. During implementation, the first lighting image may be in any proper format such as a latitude and longitude map, a cube map, a spherical map, or the like, which is not limited herein.

[0052] Since the first geometric parameter and the first reflection parameter on the surface of the object model may respectively reflect the geometric property and the light reflection property of the surface of the preset object, the object model may be used as a vertex domain that reflects ambient light. In this way, reflection and perception rendering may be performed on the preset object in at least one first image frame in the image frame sequence based on the first lighting image, and the first geometric parameter and the first reflection parameter on the surface of the object model, to obtain at least one second image frame after relighting. During implementation, reflection and perception rendering of the preset object may be achieved by using any proper rendering pipeline according to the actual situations, and the embodiments of this application are not limited thereto. For example, reflection and perception rendering may be performed on the preset object in at least one first image frame in the image frame sequence based on the first lighting image, and the first geometric parameter and the first reflection parameter on the surface of the object model by selecting a proper physical renderer according to an actual business scenario, to obtain at least one second image frame after relighting.

[0053] In some implementations, the preset object in each first image frame in the image frame sequence may be rendered, to obtain the relighted second image frame corresponding to each first image frame.

[0054] In some implementations, the preset objects in part of the first image frames in the image frame sequence may be rendered, to obtain at least one second image frame after relighting.

[0055] In the embodiments of this application, the image frame sequence including a preset object and an object model corresponding to the preset object are acquired; the first geometric parameter and a first reflection parameter on a surface of the object model are determined based on the image frame sequence; the preset object in at least one first image frame in the image frame sequence is rendered based on a preset first lighting image, the first geometric parameter, and the first reflection parameter, to obtain at least one second image frame after relighting. In this way, since the first geometric parameter and the first reflection parameter for relighting the preset object in at least first image frame in the image frame sequence are determined from the image frame sequence including the preset object, the first geometric parameter and the first reflection parameter for relighting the preset object may be determined based on the image frame sequence including preset objects of various postures, so that the preset objects of various postures can be relighted under a dynamic scenario. In addition, since the first geometric parameter and the first reflection parameter on the surface of the object model can accurately reflect a physical property of the object model, the accuracy of relighting may be enhanced, so that a more natural and realistic visual effect can be obtained. In addition, compared with the scheme in the related art of performing fine scanning and modeling on the preset object by means of professionals and expensive professional devices to achieve the relighting of the preset object, according to the embodiments of this application, the cost for relighting the preset object can be reduced, and the efficiency of relighting can be enhanced.

[0056] FIG. 2 is a schematic implementation flowchart of an image processing method according to an embodiment of this application. As shown in FIG. 2, the method includes the following S201 to S205.

[0057] At S201, an image frame sequence including a preset object and an object model corresponding to the preset object are acquired.

[0058] Herein, S201 corresponds to S101, which may refer to a specific implementation of S101 during implementation.

[0059] At S202, a feature representation of each vertex of the object model is determined.

[0060] Herein, the object model may have a plurality of vertexes. Each vertex may correspond to a key point on the preset object, and may have one feature representation. During implementation, the quantity of the vertexes on the object model and the feature representation of each vertex may be determined according to the object model actually corresponding to the preset object. During implementation, the feature representation may be implemented in any proper form, which is not limited herein. For example, the feature representation may be a multi-dimensional vector, such as a 16-dimensional vector, or a 256-dimensional vector.

[0061] In some implementations, in a case that the preset object is the human body, the object model may be a parametric human body model. The human body model may include the plurality of vertexes. Each vertex may correspond to a key point on the human body and has a feature representation. The feature representation of each vertex on the human body model may represent a human body. Herein, the human body model may include, but is not limited to, the SMPL model, SMPL-X, and the like. For example, in a case that the human body model is the SMPL model, the quantity of the vertexes in the human body model is 6890. In a case that the human body model is an SMPL-X model, the quantity of the vertexes in the human body model is 10475. During implementation, the feature representation of each vertex of the object model may be determined through random initialization, or may be trained by using a neural network, and the embodiments of this application are not limited thereto.

[0062] At S203, for each first image frame in the image frame sequence, a corresponding coordinate value of each vertex in the first image frame is determined, and each contour point on the surface of the object model in the first image frame, and the

coordinate value and the feature representation corresponding to each contour point are determined based on the feature representation of each vertex and the coordinate value corresponding to the vertex in the first image frame.

[0063] Herein, for each first image frame, the corresponding coordinate value of each vertex of the object model in the first image frame is a coordinate value of a key point on the preset object corresponding to the vertex in a three-dimensional scenario space corresponding to the first image frame. Therefore, for each first image frame, three-dimensional reconstruction may be performed on the first image frame to obtain the three-dimensional scenario space corresponding to the first image frame and the coordinate value of the key point on the preset object corresponding to each vertex in the three-dimensional scenario space, that is, the corresponding coordinate value of each vertex of the object model in the first image frame. During implementation, those skilled in the art may adopt a proper three-dimensional reconstruction algorithm to perform three-dimensional reconstruction on each first image frame according to the actual situations, and the embodiments of this application are not limited thereto. For example, in a case that a camera collecting the first image frame is a monocular camera, monocular three-dimensional reconstruction may be performed on the first image frame by using a Structure-from-Motion (SFM) algorithm, a Regularized Monocular Depth Estimation (REMODE), and the like. In a case that the camera collecting the first image frame is a binocular camera, two corrected images may be obtained by using left and right cameras, matching points of the two corrected images are determined by using a binocular matching algorithm (such as a Semi-Global Block Matching (SGBM) algorithm and a Block Matching (BM) algorithm), and then three-dimensional information of an environment is recovered according to a principle of triangulation. In a case that the camera collecting the first image frame is a color depth (RGBD) camera, RGBD three-dimensional reconstruction may be performed on the first image frame by using at least one of Kinect Fusion, Dynamic Fusion, Elastic Fusion, Fusion 4D, Volume Deform, or the like.

[0064] A surface of the object model in each first image frame may be determined through a plurality of contour points. During implementation, in each first image frame, the contour point on the surface of the object model may include a spatial point

corresponding to the vertex of the object model and a plurality of spatial points between the vertexes. In some implementations, for each first image frame, trilinear interpolation may be performed between the vertexes based on the feature representation of each vertex of the object model and the corresponding coordinate value of each vertex in the first image frame, to obtain each contour point on the surface of the object model in the first image frame. Then the coordinate value and the feature representation corresponding to each contour point can be determined. The coordinate value corresponding to each contour point may be a coordinate value of each contour point in the three-dimensional scenario space corresponding to the first image frame. In some implementations, for each first image frame, three-dimensional surface fitting may be performed based on the feature representation of each vertex of the object model and the corresponding coordinate value of each vertex in the first image frame, to obtain each contour point on the surface of the object model in the first image frame. Then the coordinate value and the feature representation corresponding to each contour point are determined. In some implementations, for each first image frame, the volume density of each spatial point in the three-dimensional scenario space corresponding to the first image frame may be determined based on the feature representation of each vertex of the object model and the corresponding coordinate value of each vertex in the first image frame. The coordinate value of each contour point on the surface of the object model in the first image frame may be determined based on the volume density of each spatial point in the three-dimensional scenario space. In this way, the feature representation of each contour point may be determined based on the feature representation of at least one vertex adjacent to each contour point.

[0065] For example, the preset object included in the image frame sequence may be expressed as a four-dimensional neural field Ψ . Each first image frame in the image frame sequence corresponds to a time point. Each contour point on the surface of the object model corresponding to the preset object corresponding to one coordinate value in each first image frame. For the first image frame corresponding to the time point t , the feature representation of the contour point, of which coordinate value in each first image frame is (x, y, z) , is $\Psi_t(x, y, z)$. For each first image frame in the image frame sequence, the four-dimensional neural field Ψ corresponding to the preset object included in the

image frame sequence may be estimated based on the feature representation of each vertex of the object model and the corresponding coordinate value of each vertex in the first image frame. Based on the estimated four-dimensional neural field ψ , the feature representation $\psi_{t1}(x1, y1, z1)$ of any spatial point $(x1, y1, z1)$ at any time point $t1$ may be determined. In this way, for each first image frame, trilinear interpolation may be performed based on the coordinate value of each vertex at the time point corresponding to the image frame and the feature representation of each vertex, to determine the coordinate value corresponding to each contour point on the surface of the object model. Based on the coordinate value of each contour point and the time point, the corresponding feature representation of each contour point at the time point may be determined by querying the four-dimensional neural field ψ , that is the corresponding feature representation of each contour point in the first image frame.

[0066] At S204, the first geometric parameter and the first reflection parameter of each contour point are determined based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame.

[0067] Herein, according to actual content included in the first geometric parameter and the first reflection parameter respectively, a proper manner may be used to determine the first geometric parameter and the first reflection parameter of each contour point based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame. The embodiments of this application are not limited thereto.

[0068] In some implementations, for each contour point on the surface of the object model in each first image frame, the first geometric parameter and the first reflection parameter of each contour point may be predicted based on the coordinate value and the feature representation corresponding to the contour point by using a first neural network, so that the predicted first geometric parameter and the first reflection parameter of each contour are obtained.

[0069] In some implementations, for each first image frame, the volume density of

each spatial point in the three-dimensional scenario space corresponding to the first image frame may be predicted based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in the first image frame by using a second neural network, and then the first geometric parameter and the first reflection parameter of each contour are determined based on the predicted volume density of each spatial point.

[0070] In some implementations, baking may be performed based on the volume density of each spatial point predicted by the second neural network, to obtain the first geometric parameter of each contour point on the surface of the object model in each first image frame.

[0071] At S205, the preset object in at least one first image frame in the image frame sequence is rendered based on a preset first lighting image, and the first geometric parameter and the first reflection parameter of each contour point on the surface of the object model in each first image frame, to obtain at least one second image frame after relighting.

[0072] Herein, S205 corresponds to S103, which may refer to a specific implementation of S103 during implementation.

[0073] In the embodiments of this application, for each first image frame in the image frame sequence, the corresponding coordinate value of each vertex in the first image frame is determined. Each contour point on the surface of the object model and the corresponding coordinate value and the feature representation of each point in the first image frame are determined based on the feature representation of each vertex and the corresponding coordinate value of each vertex in the first image frame. The first geometric parameter and the first reflection parameter of each contour point are determined based on the corresponding coordinate value and the feature representation of each contour point in each first image frame. In this way, each contour point on the surface of the object model and the corresponding coordinate value and the feature representation of each contour point in each first image frame can be rapidly and accurately determined, so that the preset object included in each image frame can be better represented by means of determined corresponding coordinate value and the

feature representation of each contour point in each first image frame. Therefore, the first geometric parameter and the first reflection parameter of each contour point can be determined more accurately, to cause a visual effect of at least one second image frame after relighting to be more natural and realistic.

[0074] In some embodiments, S203 of determining each contour point on the surface of the object model in the first image frame, and the coordinate value and the feature representation corresponding to each contour point based on the feature representation of each vertex and the coordinate value corresponding to the vertex in the first image frame may include S211 to S213.

[0075] At S211, at least one contour point on the surface of the object model in the first image frame and the coordinate value corresponding to each contour point are determined based on the corresponding coordinate value of each vertex in the first image frame.

[0076] Herein, in some implementations, trilinear interpolation may be performed between the vertexes based on the feature representation of each vertex of the object model and the corresponding coordinate value of each vertex in the first image frame, to obtain each contour point on the surface of the object model in the first image frame and the coordinate value corresponding to each contour point.

[0077] In some implementations, three-dimensional surface fitting may be performed based on the feature representation of each vertex of the object model and the corresponding coordinate value of each vertex in the first image frame, to obtain each contour point on the surface of the object model in the first image frame and the coordinate value corresponding to each contour point.

[0078] In some implementations, the volume density of each spatial point in the three-dimensional scenario space corresponding to the first image frame may be determined based on the feature representation of each vertex of the object model and the corresponding coordinate value of each vertex in the first image frame. Each contour point on the surface of the object model in the first image frame and the coordinate value of each contour point may be determined based on the volume density of each spatial

point in the three-dimensional scenario space.

[0079] At S212, at least one vertex adjacent to each contour point is determined based on the coordinate value corresponding to each contour point.

[0080] Herein, for each contour point, the at least one vertex adjacent to the contour point may be a set number of vertexes that are spatially closest to the contour point.

[0081] In some implementations, for each contour point on the surface of the object model in the first image frame, the set number of the vertexes that are spatially closest to the contour point may be determined based on the coordinate value corresponding to the contour point and the corresponding coordinate value of each vertex in the first image frame. Then, the set number of the vertexes is determined as the vertexes adjacent to the contour point. During implementation, those skilled in the art may select the appropriate set number such as 8, 16, 20 according to actual situations, and the embodiments of this application are not limited thereto. For example, 8 vertexes that are spatially closest to the contour point are determined as the vertexes adjacent to the contour point.

[0082] At S213, for each contour point, the feature representation corresponding to the contour point is determined based on the feature representation of each vertex adjacent to the contour point.

[0083] Herein, the feature representation corresponding to each contour point may be determined based on the feature representation of each vertex adjacent to the contour point. During implementation, those skilled in the art may adopt, according to actual situations, a proper manner to determine the feature representation corresponding to the contour point based on the feature representation of each vertex adjacent to the contour point, and the embodiments of this application are not limited thereto.

[0084] For example, by means of a manner of trilinear interpolation, the feature representation corresponding to the contour point may be determined based on the feature representation of each vertex adjacent to the contour point. Alternatively, a mean value between the feature representations of each vertex adjacent to the contour point may be determined as the feature representation corresponding to the contour point. A weight corresponding to the adjacent each vertex may alternatively be determined based

on the distance between the contour point and the adjacent each vertex, and the feature representation of the corresponding vertex is weighted based on the weight of the adjacent each vertex, to obtain the feature representation corresponding to the contour point.

[0085] In the above embodiment, at least one contour point on the surface of the object model in the first image frame and the coordinate value corresponding to each contour point are determined based on the corresponding coordinate value of each vertex in the first image frame. At least one vertex adjacent to each contour point is determined based on the coordinate value corresponding to each contour point. For each contour point, the feature representation corresponding to the contour point is determined based on the feature representation of each vertex adjacent to the contour point. In this way, the at least one contour point on the surface of the object model in each first image frame and the coordinate value and the feature representation corresponding to each contour point can be rapidly and accurately determined based on the corresponding coordinate value of each vertex in the first image frame and the feature representation of each vertex. Therefore, the efficiency of relighting can be further enhanced, and the accuracy of the first geometric parameter and the first reflection parameter of each contour point in each first image frame can be enhanced, thereby further improving a visual effect of at least one second image frame after relighting.

[0086] FIG. 3A is a schematic implementation flowchart of an image processing method according to an embodiment of this application. As shown in FIG. 3A, the method includes the following S301 to S307.

[0087] At S301, an image frame sequence including a preset object and an object model corresponding to the preset object are acquired.

[0088] At S302, a feature representation of each vertex of the object model is determined.

[0089] At S303, for each first image frame in the image frame sequence, a corresponding coordinate value of each vertex in the first image frame is determined, and each contour point on the surface of the object model in the first image frame, and the

coordinate value and the feature representation corresponding to each contour point are determined based on the feature representation of each vertex and the coordinate value corresponding to the vertex in the first image frame.

[0090] Herein, S301 to S303 respectively correspond to S201 to S203, which may refer to specific implementations of S201 to S203 during implementation.

[0091] At S304, the first geometric parameter and the first reflection parameter of each contour point are determined based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using a preset first neural network.

[0092] Herein, the first neural network may be a neural network with a simple structure, such as a Multilayer Perceptron (MLP), or may be a neural network with a complex structure, such as a convolutional neural network, which is not limited herein.

[0093] The first geometric parameter and the first reflection parameter of each contour point may be predicted based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the first neural network, to obtain the predicted first geometric parameter and the first reflection parameter of each contour.

[0094] During implementation, the first neural network may be an untrained neural network, or may be a trained neural network. Those skilled in the art may select an appropriate first neural network according to actual situations, and the embodiments of this application are not limited thereto.

[0095] At S305, a loss value is determined based on the first geometric parameter and the first reflection parameter of each contour point on the surface of the object model in each first image frame.

[0096] Herein, according to actual situations, the first geometric parameter and the first reflection parameter of each contour point on the surface of the object model in each first image frame may be constrained by using an appropriate constraint manner, to determine the corresponding loss value, and the embodiments of this application are not

limited thereto.

[0097] In some implementations, for each first image frame, the first image frame may be re-rendered based on the first geometric parameter and the first reflection parameter of each contour point on the surface of the object model in the first image frame, to obtain a re-rendered third image frame corresponding to the first image frame. Then, the loss value is determined based on a pixel value loss between each first image frame and each of the corresponding third image frames.

[0098] In some implementations, position disturbance may be performed on each contour point to obtain the spatial point after position disturbance corresponding to each contour point, and the first geometric parameter of the spatial point after position disturbance corresponding to each contour point on the surface of the object model in each first image frame is determined. The loss value is determined based on the loss between the first geometric parameter of each contour point and the first geometric parameter of the corresponding spatial space after position disturbance.

[0099] In some implementations, position disturbance may be performed on each contour point to obtain the spatial point after position disturbance corresponding to each contour point, and the first reflection parameter of the spatial point after position disturbance corresponding to each contour point on the surface of the object model in each first image frame is determined. The loss value is determined based on the loss between the first reflection parameter of each contour point and the first reflection parameter of the corresponding spatial space after position disturbance.

[00100] In some implementations, for each first image frame, the volume density of each spatial point in the three-dimensional scenario space corresponding to the first image frame may be predicted based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in the first image frame by using a second neural network. A second geometric parameter and a second reflection parameter of each contour point are determined based on the volume density of each predicted spatial point. The loss value may be determined based on the loss between the first geometric parameter and the second geometric parameter of each contour point and/or the loss between the first reflection parameter and the second

reflection parameter of each contour point.

[00101] At S306, a network parameter of the first neural network and the feature representation of each vertex of the object model are updated based on the loss value, and the updated first geometric parameter and the updated first reflection parameter of each contour point are obtained based on the updated first neural network and the updated feature representation of each vertex.

[00102] Herein, a manner for updating the network parameter of the first neural network and the feature representation of each vertex of the object model may be determined according to actual situations, and may include, but not limited to, at least one of a gradient descent method or a Newton momentum method, which is not limited herein.

[00103] During implementation, the network parameter of the first neural network and the feature representation of each vertex of the object model may be updated for at least one time. After the network parameter of the first neural network and the feature representation of each vertex of the object model are updated each time, the updated first geometric parameter and the updated first reflection parameter of each contour point may be obtained based on the updated first neural network and the updated feature representation of each vertex. Then, the updated loss value may be determined based on the updated first geometric parameter and the first reflection parameter of each contour point. Based on the loss value, whether the network parameter of the first neural network and the feature representation of each vertex of the object model are continuously updated for a next time may be determined.

[00104] In some implementations, in a case that the loss value meets a first preset condition or the time for updating the network parameter of the first neural network and the feature representation of each vertex of the object model is less than a time threshold, the next updating of the network parameter of the first neural network and the feature representation of each vertex of the object model is stopped. Herein, the first preset condition may include, but not limited to, the loss value being less than a preset loss threshold, change convergence between the loss values updated each time, and the like, which is not limited herein.

[00105] In some implementations, in a case that the loss value does not meet the first preset condition, the next updating of the network parameter of the first neural network and the feature representation of each vertex of the object model may be continued.

[00106] At S307, the preset object in at least one first image frame in the image frame sequence is rendered based on a preset first lighting image, and the first geometric parameter and the first reflection parameter of each contour point on the surface of the object model in each first image frame, to obtain at least one second image frame after relighting.

[00107] Herein, S307 corresponds to S205, which may refer to a specific implementation of S205 during implementation.

[00108] In an embodiment of this application, the first geometric parameter and the first reflection parameter of each contour point are determined based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using a preset first neural network. The loss value is determined based on the first geometric parameter and the first reflection parameter of each contour point on the surface of the object model in each first image frame. The network parameter of the first neural network and the feature representation of each vertex of the object model may be updated for at least one time based on the loss value, and the updated first geometric parameter and the first reflection parameter of each contour point may be obtained based on the updated first neural network and the updated feature representation of each vertex. In this way, through the constraint of the first geometric parameter and the first reflection parameter of each contour point on the surface of the object model in each first image frame, a learning capacity of the updated first neural network on the first geometric parameter and the first reflection parameter of each contour point may be strengthened, and a representational capacity of the updated feature representation of each vertex of the object model on each vertex can be enhanced. Therefore, the determined first geometric parameter and the first reflection parameter of each contour point can be more accurate, and the visual effect of the at least one second image frame after relighting can be further improved.

[00109] In some embodiments, S306 of updating the network parameter of the first

neural network and the feature representation of each vertex of the object model for at least one time may include S311.

[00110] At S311, the network parameter of the first neural network and the feature representation of each vertex of the object model are updated in a case that the loss value does not meet the first preset condition.

[00111] Herein, the first preset condition may include, but not limited to, at least one of the loss value being less than a preset loss threshold, change convergence between the loss values updated each time, or the like. During implementation, those skilled in the art may set the appropriate first preset condition according to actual situations, which is not limited herein.

[00112] In some embodiments, S306 of obtaining the updated first geometric parameter and the first reflection parameter of each contour point based on the updated first neural network and the updated feature representation of each vertex may include S321 to S322.

[00113] At S321, for each first image frame in the image frame sequence, the corresponding updated feature representation of each contour point in the first image frame is determined based on the updated feature representation of each vertex and the corresponding coordinate value of each vertex in the first image frame.

[00114] Herein, S321 corresponds to S303 of determining each contour point on the surface of the object model in the first image frame, and the coordinate value and the feature representation corresponding to each contour point based on the feature representation of each vertex and the corresponding coordinate value of the vertex in the first image frame, which may refer to a specific implementation of S303 during implementation.

[00115] At S322, the updated first geometric parameter and the updated first reflection parameter of each contour on the surface of the object model are determined based on the corresponding coordinate value of the contour point in each first image frame and the updated feature representation by using the updated first neural network.

[00116] Herein, S321 corresponds to S304, which may refer to a specific

implementation of S304 during implementation.

[00117] In some embodiments, the loss value includes a first loss value. Step S305 may include S331 to S333.

[00118] At S331, a second lighting image corresponding to the image frame sequence is determined.

[00119] Herein, the second lighting image is a lighting image corresponding to a current lighting scenario in the image frame sequence, may be predetermined according to the lighting scenario in the image frame sequence, or may be obtained through training after pre-initialization, which is not limited herein. The second lighting image may reflect a lighting intensity of each direction under the current lighting scenario in the image frame sequence. During implementation, the second lighting image may be in any proper format such as a latitude and longitude map, a cube map, a spherical map, or the like, which is not limited herein.

[00120] At S332, for each first image frame, the preset object in the first image frame is rendered based on the first geometric parameter and the first reflection parameter of each contour point on the surface of the object model in the first image frame by using the second lighting image, to obtain a third image frame after relighting.

[00121] Herein, for each first image frame, reflection and perception rendering may be performed on the preset object in the first image frame based on the second lighting image, and the first geometric parameter and the first reflection parameter of each contour point on the surface of the object model in the first image frame, to obtain the third image frame after relighting. During implementation, reflection and perception rendering of the preset object may be achieved by using any proper rendering pipeline according to the actual situations, and the embodiments of this application are not limited thereto. For example, reflection and perception rendering may be performed on the preset object in each first image frame based on the second lighting image, and the first geometric parameter and the first reflection parameter of each contour point on the surface of the object model in each first image frame by selecting a proper physical renderer according to an actual business scenario, to obtain at least one third image frame

after relighting.

[00122] At S333, the first loss value is determined based on each first image frame and each third image frame.

[00123] Herein, each first image frame may correspond to one third image frame after relighting. The first loss value may represent the loss between each first image frame and the corresponding third image frame.

[00124] During implementation, those skilled in the art may adopt a proper manner to determine the first loss value based on each first image frame and each third image frame according to actual situations, and the embodiments of this application are not limited thereto.

[00125] In some implementations, the distance between each first image frame and the corresponding third image frame may be determined. Based on each distance, the first loss value may be determined. For example, a sum of the distances between the first image frames and the corresponding third image frames may be determined as the first loss value. A mean value of the distance between each first image frame and the corresponding third image frame may alternatively be determined as the first loss value. Herein, the distance between each first image frame and the corresponding third image frame may include, but not limited to, a cosine distance, a Euclidean distance, and the like.

[00126] In some implementations, a mean square error between a color value of each pixel in each first image frame and a color value of each pixel of the third image frame corresponding to the first image frame may be determined, and the first loss value is determined according to each mean square error. For example, a sum of the mean square errors between the color values of the pixels in each first image frame and the color values of the pixels of the third image frame corresponding to the first image frame may be determined as the first loss value. Alternatively, a mean value of the mean square errors between the color values of the pixels in each first image frame and the color values of the pixels of the third image frame corresponding to the first image frame may be determined as the first loss value.

[00127] In the above embodiment, the second lighting image corresponding to the image frame sequence is determined. For each first image frame, the second lighting image is configured to render the preset object in the first image frame based on the first geometric parameter and the first reflection parameter of each contour point on the surface of the object model in the first image frame, to obtain the third image frame after relighting; and the first loss value is determined based on each first image frame and each third image frame. In this way, since the third image frame corresponding to each first image frame is obtained by rendering the preset object in the first image frame based on the second lighting image corresponding to the image frame sequence and the first geometric parameter and the first reflection parameter of each contour point on the surface of the object model in the first image frame, the first geometric parameter and the first reflection parameter of each contour point on the surface of the object model in each first image frame are constrained by means of the first loss value between each first image frame and the corresponding third image frame, so that the consistency between each first image frame and the corresponding third image frame can be maintained. Therefore, the accuracy of the determined first geometric parameter and the first reflection parameter of each contour point can be improved, thereby further enhancing the visual effect of at least one second image frame after relighting.

[00128] In some embodiments, S311 of updating the network parameter of the first neural network and the feature representation of each vertex of the object model may include the following step.

[00129] At S341, the network parameter of the first neural network, the feature representation of each vertex of the object model, and the second lighting image are updated.

[00130] Herein, a manner for updating the network parameter of the first neural network, the feature representation of each vertex of the object model, and the second lighting image may be determined according to actual situations, and may include, but not limited to, at least one of a gradient descent method or a Newton momentum method, which is not limited herein.

[00131] In some implementations, the second lighting image corresponding to the

image frame sequence may be randomly initialized in a case that the current lighting scenario in the image frame sequence is unknown. The second lighting image is updated for at least one time during the updating of the network parameter of the first neural network and the feature representation of each vertex of the object model, so as to estimate a reasonable lighting scenario for the image frame sequence.

[00132] The image processing method may further include S342 to S343.

[00133] At S342, for each first image frame, the updated second lighting image is configured to render the preset object in the first image frame based on the updated first geometric parameter and the updated first reflection parameter of each contour point on the surface of the object model in the first image frame, to obtain the updated and relighted third image frame.

[00134] At S343, the updated first loss value is determined based on each first image frame and each updated third image frame.

[00135] Herein, S342 to S343 respectively correspond to S332 to S333, which may refer to specific implementations of S332 to S333 during implementation.

[00136] In the above embodiment, the network parameter of the first neural network, the feature representation of each vertex of the object model, and the second lighting image are updated. For each first image frame, the updated second lighting image is configured to render the preset object in the first image frame based on the updated first geometric parameter and the updated first reflection parameter of each contour point on the surface of the object model in the first image frame, to obtain the updated and relighted third image frame. The updated first loss value is determined based on each first image frame and each updated third image frame. In this way, the second lighting image corresponding to the image frame sequence may be continuously updated through the constraint of the first loss value, so that a more reasonable lighting scenario can be estimated for the image frame sequence. Therefore, the accuracy of the updated first geometric parameter and the first reflection parameter of each contour point can be further improved, to cause the visual effect of at least one second image frame after relighting to be more natural and realistic.

[00137] In some embodiments, the loss value further includes a second loss value. Step S305 may further include S351 to S353.

[00138] At S351, a second geometric parameter of each contour point is determined based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using a preset second neural network.

[00139] Herein, the second geometric parameter may be any proper parameter that can characterize the geometric property on the surface of the object model, and includes, but is not limited to, at least one of a normal, the light visibility, or the like. During implementation, parameter content included in the second geometric parameter may be determined according to parameter content actually included in the first geometric parameter, which is not limited herein. For example, in a case that the first geometric parameter includes the normal, the second geometric parameter may also include the normal. In a case that the first geometric parameter includes the light visibility, the second geometric parameter may also include the light visibility.

[00140] The second neural network may be a neural network with a simple structure, such as an MLP, or may be a neural network with a complex structure, such as a convolutional neural network, which is not limited herein.

[00141] The second geometric parameter of each contour point may be predicted based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the second neural network, to obtain the predicted second geometric parameter of each contour.

[00142] During implementation, the second neural network may be an untrained neural network, or may be a trained neural network. Those skilled in the art may select an appropriate second neural network according to actual situations, and the embodiments of this application are not limited thereto.

[00143] At S352, the second loss value is determined based on the first geometric parameter and the second geometric parameter of each contour point.

[00144] Herein, the second loss value may represent the loss between the first geometric parameter and the second geometric parameter of each contour point on the surface of the object model in each first image frame. During implementation, the second loss value may be determined based on the first geometric parameter and the second geometric parameter of each contour point by using any proper manner, and the embodiments of this application are not limited thereto.

[00145] In some implementations, the second loss value may be determined based on the distance between the first geometric parameter and the second geometric parameter of each contour point. Herein, the distance between the first geometric parameter and the second geometric parameter of each contour point may include, but not limited to, at least one of a cosine distance, a Euclidean distance, or the like.

[00146] In some implementations, the second loss value may be determined based on a mean square error between the first geometric parameter and the second geometric parameter of each contour point.

[00147] In some implementations, in a case that the first geometric parameter includes a first normal and first light visibility and the second geometric parameter includes a second normal and second light visibility, the second loss value L_{geo} may be determined based on a root mean square error between the first normal $n(p)$ and the second normal $\tilde{n}(p)$ of each contour point P and a root mean square error between the first light visibility $V(p)$ and the second light visibility $\tilde{V}(p)$ of each contour point P by using a manner shown as a formula 1:

$$L_{geo} = \|n(p) - \tilde{n}(p)\|_2^2 + \|V(p) - \tilde{V}(p)\|_2^2 \quad (1).$$

[00148] In the above embodiment, the second geometric parameter of each contour point is determined based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the preset second neural network; and the second loss value is determined based on the first geometric parameter and the second geometric parameter of

each contour point. In this way, by means of the second loss value between the first geometric parameter and the second geometric parameter of each contour point, the first geometric parameter and the first reflection parameter of each contour point on the surface of the object model in each first image frame are constrained. Therefore, the accuracy of the determined first geometric parameter and the first reflection parameter of each contour point can be improved, thereby further enhancing the visual effect of at least one second image frame after relighting.

[00149] In some embodiments, S351 may include S361 to S365.

[00150] At S361, for each first image frame, at least one first spatial point corresponding to each contour point is determined based on the coordinate value corresponding to each contour point on the surface of the object model in the first image frame. The first spatial point corresponding to each contour point is a spatial point of a light source corresponding to the image frame sequence along incident light of the contour point.

[00151] Herein, the light source corresponding to the image frame sequence may be determined according to the lighting scenario in the image frame sequence, or may be designed for the image frame sequence in advance. The embodiments of this application are not limited thereto.

[00152] Incident light of the light source may be received at each contour point on the surface of the object model in each first image frame. At least one first spatial point corresponding to each contour point may be sampled from the incident light of the light source at the contour point. During implementation, the at least one first spatial point corresponding to each contour point may be sampled from the incident light of the light source at each contour point by using any proper manner, which is not limited herein. For example, a set number of the first spatial points may be sampled from each spatial point on the incident light of the light source at each contour point by using a manner of uniform sampling.

[00153] In some implementations, for each contour point, the incident light of the light source at the contour point may be determined, and a set number of the first spatial points

is sampled from a plurality of spatial points on the incident light of which distance from the contour point meets a first preset distance condition. Herein, the first preset distance condition may include, but not limited to, at least one of being greater than a first distance threshold, or being less than a second distance threshold. The first distance threshold and the second distance threshold may be preset, or may be determined according to the lighting scenario in the image frame sequence, which is not limited herein. The first distance threshold may be less than the second distance threshold. For example, the first distance threshold may be 0.2, and the second distance threshold may be 1.5.

[00154] At S362, a feature representation of each first spatial point is determined based on the feature representation of each vertex and the coordinate value corresponding to the vertex in each first image frame.

[00155] Herein, for each first spatial point, at least one vertex adjacent to the first spatial point may be determined based on the corresponding coordinate value of each vertex in each first image frame, and the feature representation corresponding to the first spatial point is determined based on the feature representation of each vertex adjacent to the first spatial point. During implementation, those skilled in the art may adopt, according to actual situations, a proper manner to determine the feature representation corresponding to the first spatial point based on the feature representation of each vertex adjacent to the first spatial point, and the embodiments of this application are not limited thereto.

[00156] For example, by means of a manner of trilinear interpolation, the feature representation corresponding to the first spatial point may be determined based on the feature representation of each vertex adjacent to the first spatial point. Alternatively, a mean value between the feature representations of each vertex adjacent to the first spatial point may be determined as the feature representation corresponding to the first spatial point. Alternatively, a weight corresponding to the adjacent each vertex may be determined based on the distance between the first spatial point and the adjacent each vertex, and the feature representation of the corresponding vertex is weighted based on the weight of the adjacent each vertex, to obtain the feature representation corresponding

to the first spatial point.

[00157] At S363, a volume density of each first spatial point is determined based on the feature representation of each first spatial point by using the preset second neural network.

[00158] Herein, the volume density of the spatial point may be determined based on the feature representation of any spatial point in the three-dimensional scenario space corresponding to the image frame sequence by using the second neural network. In this way, the volume density of each first spatial point may be determined based on the feature representation of each first spatial point by using the second neural network.

[00159] In some implementations, the second neural network may be a density field that represents a mapping relationship between the feature representation of each spatial point in the three-dimensional scenario space corresponding to the image frame sequence and the volume density. The volume density of each spatial point may be obtained by querying the density field based on the feature representation of each first spatial point.

[00160] At S364, a second geometric parameter of each contour point is determined based on the volume density of at least one first spatial point corresponding to each contour point.

[00161] Herein, the volume density of at least one first spatial point corresponding to each contour point may reflect a light transmission property near the contour point. The light transmission property near the contour point may reflect a geometric feature at the contour point, such as the normal, the light visibility, and the like. Therefore, the second geometric parameter of each contour point may be determined based on the volume density of at least one first spatial point corresponding to each contour point.

[00162] During implementation, those skilled in the art may adopt, according to actual situations, a proper manner to determine the second geometric parameter of each contour point based on the volume density of at least one first spatial point corresponding to each contour point, which is not limited herein.

[00163] Step S311 of updating the network parameter of the first neural network and

the feature representation of each vertex of the object model may include the following step.

[00164] At S365, the network parameter of the first neural network, a network parameter of the second neural network, and the feature representation of each vertex of the object model are updated.

[00165] Herein, a manner for updating the network parameter of the first neural network, the network parameter of the second neural network, and the feature representation of each vertex of the object model may be determined according to actual situations, and may include, but not limited to, at least one of a gradient descent method or a Newton momentum method, which is not limited herein.

[00166] In the above embodiment, for each first image frame, at least one first spatial point corresponding to each contour point is determined based on the coordinate value corresponding to each contour point on the surface of the object model in the first image frame. The feature representation of each first spatial point is determined based on the feature representation of each vertex and the corresponding coordinate value of each vertex in each first image frame. The volume density of each first spatial point is determined based on the feature representation of each first spatial point by using the preset second neural network. The second geometric parameter of each contour point is determined based on the volume density of at least one first spatial point corresponding to each contour point. In this way, the second geometric parameter of each contour point on the surface of the object model in each first image frame can be rapidly and accurately determined. In addition, the network parameter of the second neural network is also updated during the updating of the network parameter of the first neural network and the feature representation of each vertex of the object model, so that the network parameter of the second neural network can be continuously optimized. Therefore, the volume density of each first spatial point can be determined more accurately, thereby further enhancing the accuracy of the second geometric parameter of each contour point.

[00167] In some embodiments, S363 may include at least one of S371 or S372.

[00168] At S371, in a case that the second geometric parameter includes a second

normal, a volume density gradient corresponding to each contour point in each first image frame is determined based on the volume density of at least one first spatial point corresponding to each contour point, and a second normal of each contour point is determined based on the volume density gradient corresponding to each contour point in each first image frame.

[00169] Herein, for each contour point on the surface of the object model in each first image frame, the second normal of the contour point may be determined based on the volume density gradient corresponding to the contour point in the first image frame.

[00170] In some implementations, for each contour point on the surface of the object model in each first image frame, a negative volume density gradient corresponding to the contour point in the first image frame may be determined as the second normal of the contour point.

[00171] In some implementations, for each contour point on the surface of the object model in each first image frame, the negative normalization of the volume density gradient corresponding to the contour point in the first image frame may be determined as the second normal of the contour point. For example, a manner shown as a formula 2 may be used to determine the negative normalization of the volume density gradient corresponding to the contour point in the first image frame as the second normal of the contour point.

$$\tilde{n}(p) = -\frac{\nabla \sigma(p)}{\|\nabla \sigma(p)\|} \quad (2).$$

$\sigma(p)$ is the volume density of the contour point P on the surface of the object model in the first image frame; $\nabla \sigma(p)$ is the volume density gradient of the contour point P ; and $\tilde{n}(p)$ is the negative normalization of the volume density gradient corresponding to the contour point P in the first image frame, that is, the second normal of the contour point P .

[00172] At S372, in a case that the second geometric parameter includes light visibility,

for each contour point, cumulative transmittance of each first spatial point is determined based on the volume density of at least first spatial point corresponding to the contour point, and second light visibility of the contour point is determined based on the cumulative transmittance and the volume density of each first spatial point.

[00173] Herein, the second light visibility of each contour point in each first image frame may be determined based on the cumulative transmittance and the volume density of each first spatial point corresponding to the contour point.

[00174] For each contour point, the cumulative transmittance of each first spatial point corresponding to the contour point may be cumulative transmittance of the volume density of each first spatial point on a path from the contour point to the current first spatial point along a direction opposite to the incident light corresponding to the contour point.

[00175] In some implementations, for each first spatial point corresponding to each contour point, the cumulative transmittance of the current first spatial point may be determined based on the volume density of each first spatial point between the contour point and the current first spatial point.

[00176] For example, a manner shown as a formula 3 may be used to determine the cumulative transmittance $T(s)$ of the first spatial point S corresponding to the contour point P .

$$T(s) = \exp\left(-\int_{s_n}^s \sigma(r(t))dt\right) \quad (3).$$

t is the first spatial point between a near boundary point s_n of the contour point P in a direction corresponding to the incident light at the contour point P and the current first spatial point s ; $r(t)$ is the coordinate value of the first spatial point t ; $\sigma(r(t))$ is the volume density of the first spatial point t ; and the near boundary point s_n of the contour point P is a spatial point of which distance from the contour point P is the preset first distance threshold in the direction opposite to the incident light corresponding to the

contour point P .

[00177] FIG. 3B is a schematic diagram of light at a contour point on a surface of an object model according to an embodiment of this application. As shown in FIG. 3B, for the contour point P , the normal of the contour point P is $n(p)$. s_n and s_f are the near boundary point and a far boundary point of the contour point P , respectively. The near boundary point s_n is the spatial point of which distance from the contour point P is the preset first distance threshold in the direction $-w_i$ opposite to the incident light w_i corresponding to the contour point P . The far boundary point s_f is a spatial point of which distance from the contour point P is the preset second distance threshold in a direction $-w_i$. Along the incident light w_i at the contour point P , at least one first spatial point s corresponding to the contour point P may be sampled between the near boundary point s_n and the far boundary point s_f .

[00178] For each contour point, the second light visibility of the contour point may be determined based on the cumulative transmittance and the volume density of each first spatial point corresponding to the contour point.

[00179] In some implementations, for each contour point, the cumulative transmittance of each first spatial point corresponding to the contour point may be used as the weight of the corresponding first spatial point, to calculate a weighted value of the volume density of each first spatial point, and the second light visibility of the contour point may be determined based on the weighted value. For example, a manner shown as a formula 4 may be used to determine the second light visibility $\tilde{V}(p, w_i)$ of the contour point P :

$$\tilde{V}(p, w_i) = 1 - \int_{s_n}^{s_f} T(s) \sigma(r(s, p, w_i)) ds \quad (4).$$

s_n and s_f respectively are the near boundary point and a far boundary point of the contour point P in a $-w_i$ direction; $T(s)$ is the cumulative transmittance of the first

spatial point s ; $r(s, p, w_i)$ is a coordinate value of the first spatial point s of the light source corresponding to the image frame sequence on the incident light w_i of the contour point p ; and $\sigma(r(s, p, w_i))$ is the volume density of the first spatial point s .

[00180] In some embodiments, S303 of determining each contour point on the surface of the object model in the first image frame based on the feature representation of each vertex and the coordinate value corresponding to the vertex in the first image frame may include S381 to S384.

[00181] At S381, for each camera light in at least one preset camera light, at least one second spatial point is determined along the camera light.

[00182] Herein, the camera light may be a ray emitted from a camera in the three-dimensional scenario space corresponding to the image frame sequence. At least one camera light may be predetermined according to coordinates (that is, a camera original point) of the camera corresponding to the image frame sequence in the three-dimensional scenario space.

[00183] In some implementations, for each camera light, at least one second spatial point may be sampled along the camera light. During implementation, the at least one second spatial point may be sampled from each camera light by using any proper manner, which is not limited herein. For example, a set number of the second spatial points may be sampled from each spatial point on each camera light by using a manner of uniform sampling.

[00184] In some implementations, for each camera light, a set number of the second spatial points is sampled from a plurality of spatial points on the camera light of which distance from the camera original point meets a second preset distance condition. Herein, the second preset distance condition may include, but not limited to, at least one of being greater than a third distance threshold, or being less than a fourth distance threshold. The third distance threshold and the fourth distance threshold may be preset, or may be determined according to the lighting scenario in the image frame sequence, which is not limited herein. The third distance threshold may be less than the fourth distance threshold.

For example, the third distance threshold may be 0.25, and the fourth distance threshold may be 1.75.

[00185] As shown in FIG. 3B, for the camera light $^{-w_0}$ starting from the camera original point x , at least one second spatial point q may be sampled along the camera light $^{-w_0}$.

[00186] At S382, a feature representation of each second spatial point is determined based on the feature representation of each vertex and the coordinate value corresponding to the vertex in the first image frame.

[00187] Herein, for each second spatial point, at least one vertex adjacent to the second spatial point may be determined based on the coordinate value corresponding to each vertex in each first image frame, and the feature representation corresponding to the second spatial point is determined based on the feature representation of each vertex adjacent to the second spatial point. During implementation, those skilled in the art may adopt, according to actual situations, a proper manner to determine the feature representation corresponding to the second spatial point based on the feature representation of each vertex adjacent to the second spatial point, which is not limited herein.

[00188] For example, by means of a manner of trilinear interpolation, the feature representation corresponding to the second spatial point may be determined based on the feature representation of each vertex adjacent to the second spatial point. Alternatively, a mean value between the feature representations of each vertex adjacent to the second spatial point may be determined as the feature representation corresponding to the second spatial point. A weight corresponding to the adjacent each vertex may alternatively be determined based on the distance between the second spatial point and the adjacent each vertex, and the feature representation of the corresponding vertex is weighted based on the weight of the adjacent each vertex, to obtain the feature representation corresponding to the second spatial point.

[00189] At S383, the volume density corresponding to each second spatial point in the

first image frame is determined based on the feature representation of each second spatial point by using the second neural network.

[00190] Herein, the volume density of the spatial point may be determined based on the feature representation of any spatial point in the three-dimensional scenario space corresponding to the image frame sequence by using the second neural network. In this way, the volume density of each second spatial point may be determined based on the feature representation of each second spatial point by using the second neural network.

[00191] At S384, for each camera light, the contour point on the surface of the object model is determined based on the volume density of each second spatial point on the camera light.

[00192] Herein, for each camera light, the contour point on the surface of the object model corresponding to the camera light may be determined according to the distribution of the volume density of each second spatial point on the camera light.

[00193] In some implementations, for each camera light, a weighted average between the volume densities of the second spatial points on the camera light may be determined, and the second spatial point of which volume density matching the weighted average on the camera light is determined as the contour point.

[00194] In the above embodiment, for each camera light in at least one preset camera light, at least one second spatial point is determined on the camera light. The feature representation of each second spatial point is determined based on the feature representation of each vertex and the coordinate value corresponding to the vertex in the first image frame. The volume density corresponding to each second spatial point in the first image frame is determined based on the feature representation of each second spatial point by using the second neural network. For each camera light, the contour point on the surface of the object model is determined based on the volume density of each second spatial point on the camera light. In this way, the contour points on the surface of the object model in each first image frame may be rapidly and accurately determined. Therefore, the efficiency and accuracy of relighting may be further enhanced, so as to achieve a natural and realistic visual effect.

[00195] In some embodiments, the first neural network includes a first prediction network and a second prediction network. Step S304 may include S391 to S392.

[00196] At S391, the first geometric parameter of each contour point is determined based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the preset first prediction network.

[00197] At S392, the first reflection parameter of each contour point is determined based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the preset second prediction network.

[00198] Herein, the first neural network, and the second neural network may both be neural networks with simple structures, such as MLPs, or may be neural networks with complex structures, such as convolutional neural networks. During implementation, those skilled in the art may use the proper first prediction network and the second prediction network according to actual situations, which is not limited herein.

[00199] The first geometric parameter of each contour point may be predicted based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the first prediction network, to obtain the predicted first geometric parameter of each contour.

[00200] The first reflection parameter of each contour point may be predicted based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the second prediction network, to obtain the predicted first reflection parameter of each contour.

[00201] In some embodiments, the first prediction network includes a first sub-network and a second sub-network. The first geometric parameter includes a first normal and first light visibility. Step S391 may include S3101 to S3102.

[00202] At S3101, a first normal of each contour point is determined based on the coordinate value and the feature representation corresponding to each contour point on

the surface of the object model in each first image frame by using the first sub-network.

[00203] At S3102, first light visibility of each contour point is determined based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the second sub-network.

[00204] Herein, the first sub-network, and the second sub-network may both be neural networks with simple structures, such as MLPs, or may be neural networks with complex structures, such as convolutional neural networks. During implementation, those skilled in the art may use the proper first sub-network and the second sub-network according to actual situations, which is not limited herein.

[00205] The normal at each contour point may be predicted based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the first sub-network, to obtain the predicted first normal of each contour.

[00206] The light visibility at each contour point may be predicted based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the second sub-network, to obtain the predicted first light visibility of each contour.

[00207] In the above embodiment, the first geometric parameter includes the first normal and the first light visibility. The first normal of each contour point is determined based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the first sub-network. The first light visibility of each contour point is determined based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the second sub-network. In this way, in a process of rendering the preset object in at least one first image frame in the image frame sequence to obtain at least one second image frame after relighting, the first normal, the first light visibility, and the first reflection parameter of each contour point on the surface of the object model in each first image frame are

comprehensively considered. Therefore, the visual effect of the relighted second image frame can be further improved.

[00208] In some embodiments, the loss value further includes a third loss value. Step S305 may further include S3111 to S3113.

[00209] At S3111, for each first image frame, a coordinate value and a feature representation of a third spatial point corresponding to each contour point on the surface of the object model in the first image frame are determined based on the feature representation of each vertex and the coordinate value corresponding to the vertex in the first image frame. The third spatial point corresponding to each contour point is obtained by performing position disturbance on each contour point.

[00210] Herein, position disturbance may be performed on each contour point to obtain the third spatial point. Each third spatial point may be obtained by performing position disturbance on the corresponding contour point. During implementation, position disturbance may be performed on each contour point by using any proper disturbance manner, and the embodiments of this application are not limited thereto.

[00211] In some implementations, for each contour point, a disturbance coordinate value $\varepsilon = (x', y', z')$ may be added in the coordinate value $p = (x, y, z)$ of the contour point, to obtain the coordinate value $(x + x', y + y', z + z')$ of the corresponding third spatial point. Herein, the disturbance coordinate value ε may be randomly determined. For example, each disturbance coordinate value may be sampled from a Gaussian distribution with a mean value being zero and standard deviation being 0.01.

[00212] For each third spatial point, at least one vertex adjacent to the third spatial point may be determined based on the coordinate value corresponding to each vertex in each first image frame, and the feature representation corresponding to the third spatial point is determined based on the feature representation of each vertex adjacent to the third spatial point. During implementation, those skilled in the art may adopt, according to actual situations, a proper manner to determine the feature representation corresponding to the third spatial point based on the feature representation of each vertex adjacent to the third spatial point, and the embodiments of this application are not limited

thereto. For example, the feature representation corresponding to each third spatial point may be determined by using a manner of trilinear interpolation.

[00213] At S3112, a first normal of each third spatial point is determined based on the coordinate value and the feature representation of the third spatial point corresponding to each contour point on the surface of the object model in each first image frame by using the first sub-network.

[00214] Herein, the first sub-network may predict the normal at the spatial point based on the coordinate value and the feature representation of any spatial point. Therefore, a normal direction at each third spatial point may be predicted based on the coordinate value and the feature representation of the third spatial point corresponding to each contour point on the surface of the object model in each first image frame by using the first sub-network, to obtain the predicted first normal of each third spatial point.

[00215] At S3113, the third loss value is determined based on the first normal of each contour point and the first normal of the third spatial point corresponding to each contour point.

[00216] Herein, the third loss value may represent the loss between the first normal of each contour point and the first normal of the corresponding third spatial point. During implementation, the loss between the first normal of each contour point and the first normal of the corresponding third spatial point may be determined by using any proper manner, to obtain the third loss value. The embodiments of this application are not limited thereto. For example, for the contour point P , a difference between the first normal of the contour point P and the first normal of the corresponding third spatial point $P + \varepsilon_1$ is modeled to obtain the third loss value τ_v , which may be in accordance with the following formula 5:

$$\tau_n = |n(p) - n(p + \varepsilon_1)| \quad (5).$$

[00217] In the above embodiment, for each first image frame, a coordinate value and a feature representation of a third spatial point corresponding to each contour point on the surface of the object model in the first image frame are determined based on the feature

representation of each vertex and the coordinate value corresponding to the vertex in the first image frame. The first normal of each third spatial point is determined based on the coordinate value and the feature representation of the third spatial point corresponding to each contour point on the surface of the object model in each first image frame by using the first sub-network. The third loss value is determined based on the first normal of each contour point and the first normal of the third spatial point corresponding to each contour point. In this way, since the third spatial point corresponding to each contour point is obtained by performing position disturbance on the corresponding contour point, the network parameters of the first sub-network, the second sub-network, and the second prediction network, and the feature representation of each vertex of the object model are updated through the constraint of the third loss value. Therefore, the local smoothness of the normal of each contour point on the surface of the object model in each first image frame can be enhanced, thereby further improving the visual effect of the relighted second image frame.

[00218] In some embodiments, the loss value further includes a fourth loss value. Step S305 may further include S3121 to S3123.

[00219] At S3121, for each first image frame, a coordinate value and a feature representation of a fourth spatial point corresponding to each contour point on the surface of the object model in the first image frame are determined based on the feature representation of each vertex and the coordinate value corresponding to the vertex in the first image frame. The fourth spatial point corresponding to each contour point is obtained by performing position disturbance on each contour point.

[00220] Herein, each fourth spatial point may be obtained by performing position disturbance on the corresponding contour point. During implementation, position disturbance may be performed on each contour point by using any proper disturbance manner. The used disturbance manner for determining the fourth spatial point may be same or different from the used disturbance manner for determining the third spatial point. The embodiments of this application are not limited thereto.

[00221] For each fourth spatial point, at least one vertex adjacent to the fourth spatial point may be determined based on the coordinate value corresponding to each vertex in

each first image frame, and the feature representation corresponding to the fourth spatial point is determined based on the feature representation of each vertex adjacent to the fourth spatial point. During implementation, those skilled in the art may adopt, according to actual situations, a proper manner to determine the feature representation corresponding to the fourth spatial point based on the feature representation of each vertex adjacent to the fourth spatial point, and the embodiments of this application are not limited thereto. For example, the feature representation corresponding to each fourth spatial point may be determined by using a manner of trilinear interpolation.

[00222] At S3122, first light visibility of each fourth spatial point is determined based on the coordinate value and the feature representation of the fourth spatial point corresponding to each contour point on the surface of the object model in each first image frame by using the second sub-network.

[00223] Herein, the second sub-network may predict the light visibility at the spatial point based on the coordinate value and the feature representation of any spatial point. Therefore, the light visibility at each fourth spatial point may be predicted based on the coordinate value and the feature representation of the fourth spatial point corresponding to each contour point on the surface of the object model in each first image frame by using the second sub-network, to obtain the predicted first light visibility of each fourth spatial point.

[00224] At S3123, the fourth loss value is determined based on the first light visibility of each contour point and the first light visibility of the fourth spatial point corresponding to each contour point.

[00225] Herein, the fourth loss value may represent the loss between the first light visibility of each contour point and the first light visibility of the corresponding fourth spatial point. During implementation, the loss between the first light visibility of each contour point and the first light visibility of the corresponding fourth spatial point may be determined by using any proper manner, to obtain the fourth loss value. The embodiments of this application are not limited thereto.

[00226] For example, for the contour point P , a difference between the first light

visibility of the contour point P and the first light visibility of the corresponding fourth spatial point $P + \varepsilon_2$ is modeled to obtain the fourth loss value τ_v , which may be in accordance with the following formula 6:

$$\tau_v = |V(p) - V(p + \varepsilon_2)| \quad (6).$$

[00227] In the above embodiment, for each first image frame, the coordinate value and the feature representation of the fourth spatial point corresponding to each contour point on the surface of the object model in the first image frame are determined based on the feature representation of each vertex and the coordinate value corresponding to the vertex in the first image frame. The first light visibility of each fourth spatial point is determined based on the coordinate value and the feature representation of the fourth spatial point corresponding to each contour point on the surface of the object model in each first image frame by using the second sub-network. The fourth loss value is determined based on the first light visibility of each contour point and the first light visibility of the fourth spatial point corresponding to each contour point. In this way, since the fourth spatial point corresponding to each contour point is obtained by performing position disturbance on the corresponding contour point, the network parameters of the first sub-network, the second sub-network, and the second prediction network, and the feature representation of each vertex of the object model are updated through the constraint of the fourth loss value. Therefore, the local smoothness of the light visibility of each contour point on the surface of the object model in each first image frame can be enhanced, thereby further improving the visual effect of the relighted second image frame.

[00228] In some embodiments, the second prediction network includes a third sub-network and a fourth sub-network. The first reflection parameter includes a first diffuse reflection parameter and a specular reflection parameter. Step S392 may include S3131 to S3132.

[00229] At S3131, a first diffuse reflection parameter of each contour point is determined based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the third sub-network.

[00230] At S3132, a specular reflection parameter of each contour point is determined based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the fourth sub-network.

[00231] Herein, the third sub-network and the fourth sub-network may both be neural networks with simple structures, such as MLPs, or may be neural networks with complex structures, such as convolutional neural networks. During implementation, those skilled in the art may use the proper third sub-network and the fourth sub-network according to actual situations, which is not limited herein.

[00232] The diffuse reflection parameter of each contour point may be predicted based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the third sub-network, to obtain the predicted first diffuse reflection parameter of each contour.

[00233] The specular reflection parameter of each contour point may be predicted based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the fourth sub-network, to obtain the predicted specular reflection parameter of each contour.

[00234] In the above embodiment, the first reflection parameter includes the first diffuse reflection parameter and the specular reflection parameter. The first diffuse reflection parameter of each contour point is determined based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the third sub-network. The specular reflection parameter of each contour point is determined based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the fourth sub-network. In this way, in a process of rendering the preset object in at least one first image frame in the image frame sequence to obtain at least one second image frame after relighting, the first geometric parameter, the first diffuse reflection parameter, and the specular reflection parameter of each contour point on the surface of the object model in each first image frame are comprehensively considered. Therefore, the visual effect of the relighted second image

frame may further be improved.

[00235] In some embodiments, the loss value further includes a fifth loss value. Step S305 may further include S3141 to S3143.

[00236] At S3141, for each first image frame, a coordinate value and a feature representation of a fifth spatial point corresponding to each contour point on the surface of the object model in the first image frame are determined based on the feature representation of each vertex and the coordinate value corresponding to the vertex in the first image frame, and the fifth spatial point corresponding to each contour point is obtained by performing position disturbance on each contour point.

[00237] Herein, each fifth spatial point may be obtained by performing position disturbance on the corresponding contour point. During implementation, position disturbance may be performed on each contour point by using any proper disturbance manner. The used disturbance manner for determining the fifth spatial point may be same or different from the used disturbance manner for determining the third spatial point. The embodiments of this application are not limited thereto.

[00238] For each fifth spatial point, at least one vertex adjacent to the fifth spatial point may be determined based on the coordinate value corresponding to each vertex in each first image frame, and the feature representation corresponding to the fifth spatial point is determined based on the feature representation of each vertex adjacent to the fifth spatial point. During implementation, those skilled in the art may adopt, according to actual situations, a proper manner to determine the feature representation corresponding to the fifth spatial point based on the feature representation of each vertex adjacent to the fifth spatial point, and the embodiments of this application are not limited thereto. For example, the feature representation corresponding to each fifth spatial point may be determined by using a manner of trilinear interpolation.

[00239] At S3142, a first diffuse reflection parameter of each fifth spatial point is determined based on the coordinate value and the feature representation of the fifth spatial point corresponding to each contour point on the surface of the object model in each first image frame by using the third sub-network.

[00240] Herein, the third sub-network may predict the diffuse reflection parameter at the spatial point based on the coordinate value and the feature representation of any spatial point. The diffuse reflection parameter of each fifth spatial point may be predicted based on the coordinate value and the feature representation of the fifth spatial point corresponding to each contour point on the surface of the object model in each first image frame by using the third sub-network, to obtain the predicted first diffuse reflection parameter of each fifth spatial point.

[00241] At S3143, the fifth loss value is determined based on the first diffuse reflection parameter of each contour point and the first diffuse reflection parameter of the fifth spatial point corresponding to each contour point.

[00242] Herein, the fifth loss value may represent the loss between the first diffuse reflection parameter of each contour point and the first diffuse reflection parameter of the corresponding fifth spatial point. During implementation, the loss between the first diffuse reflection parameter of each contour point and the first diffuse reflection parameter of the corresponding fifth spatial point may be determined by using any proper manner, to obtain the fifth loss value. The embodiments of this application are not limited thereto.

[00243] For example, for the contour point P , a difference between the first diffuse reflection parameter $A(p)$ of the contour point P and the first diffuse reflection parameter $A(p + \varepsilon_3)$ of the corresponding fifth spatial point $P + \varepsilon_3$ is modeled to obtain the fifth loss value τ_A , which may be in accordance with the following formula 7:

$$\tau_A = |A(p) - A(p + \varepsilon_3)| \quad (7).$$

[00244] In the above embodiment, for each first image frame, the coordinate value and the feature representation of the fifth spatial point corresponding to each contour point on the surface of the object model in the first image frame are determined based on the feature representation of each vertex and the coordinate value corresponding to the vertex in the first image frame. The first diffuse reflection parameter of each fifth spatial point is determined based on the coordinate value and the feature representation of the fifth

spatial point corresponding to each contour point on the surface of the object model in each first image frame by using the third sub-network. The fifth loss value is determined based on the first diffuse reflection parameter of each contour point and the first diffuse reflection parameter of the fifth spatial point corresponding to each contour point. In this way, since the fifth spatial point corresponding to each contour point is obtained by performing position disturbance on the corresponding contour point, the network parameters of the first prediction network, the third sub-network, and the fourth sub-network, and the feature representation of each vertex of the object model are updated through the constraint of the fifth loss value. Therefore, the local smoothness of the diffuse reflection parameter of each contour point on the surface of the object model in each first image frame may be enhanced, thereby further improving the visual effect of the relighted second image frame.

[00245] In some embodiments, the loss value may include the first loss value, the second loss value, the third loss value, the fourth loss value, and the fifth loss value. During implementation, the first loss value, the second loss value, the third loss value, the fourth loss value, and the fifth loss value may be weighted according to different weights, respectively, to obtain a total loss value. The weights to which the first loss value, the second loss value, the third loss value, the fourth loss value, and the fifth loss value correspond, respectively, may be set according to actual situations, which are not limited herein.

[00246] In this way, in a process of updating the network parameters of the first sub-network, the second sub-network, the third sub-network, and the fourth sub-network, and the feature representation of each vertex of the object model, the first loss value, the second loss value, the third loss value, the fourth loss value, and the fifth loss value are comprehensively considered. Therefore, the local smoothness of the diffuse reflection parameter of each contour point on the surface of the object model in each first image frame may be enhanced, thereby causing the visual effect of the relighted second image frame to be more natural and realistic.

[00247] FIG. 4 is a schematic implementation flowchart of an image processing method according to an embodiment of this application. As shown in FIG. 4, the method

includes S401 to S403.

[00248] At S401, an image frame sequence including a preset object and an object model corresponding to the preset object are acquired.

[00249] At S402, a first geometric parameter and a first reflection parameter on a surface of the object model are determined based on the image frame sequence. The first geometric parameter on the surface of the object model includes the first geometric parameter of each contour point on the surface of the object model in each first image frame. The first reflection parameter on the surface of the object model includes the first reflection parameter of each contour point on the surface of the object model in each first image frame.

[00250] Herein, S401 to S402 respectively correspond to S101 to S102, which may refer to specific implementations of S101 to S102 during implementation.

[00251] At S403, for each of the at least one first image frame, by using a preset physical renderer, the preset object in the first image frame is rendered based on the preset first lighting image, and the first geometric parameter and the first reflection parameter of each contour point on the surface of the object model in the first image frame, to obtain the second image frame after relighting.

[00252] Herein, the physical renderer is a rendering engine that performs image rendering based on physical properties of real light. During implementation, those skilled in the art may select the appropriate physical renderer according to actual situations, and the embodiments of this application are not limited thereto.

[00253] The physical renderer may adopt an appropriate rendering pipeline, and modeling is performed on a process of reflection and perception rendering, so that the preset object in the first image frame may be rendered based on the preset first lighting image, and the first geometric parameter and the first reflection parameter of each contour point on the surface of the object model in the first image frame, to obtain the second image frame after relighting.

[00254] In an embodiment of this application, for each of the at least one first image

frame, by using a preset physical renderer, the preset object in the first image frame is rendered based on the preset first lighting image, and the first geometric parameter and the first reflection parameter of each contour point on the surface of the object model in the first image frame, to obtain the second image frame after relighting. In this way, the visual effect of the relighted second image frame may be more natural and realistic based on the physical renderer.

[00255] In some embodiments, the first geometric parameter includes the first normal and the first light visibility of each contour point on the surface of the object model in each first image frame. Step S403 may include S411 to S413.

[00256] At S411, a Bidirectional Reflectance Distribution Function (BRDF) of the object model is determined based on the first normal and the first reflection parameter of each contour point on the surface of the object model in the first image frame.

[00257] Herein, the BRDF is a function for defining how irradiance in a given incident direction affects radiance in a given emitting direction. The function describes the distribution of the incident light in each emitting direction after being reflected by a certain surface. The reflection on the surface may range from ideal specular reflection to diffuse reflection, isotropic reflection or anisotropic reflection.

[00258] During implementation, the distribution of the incident light in each emitting direction after being reflected by the certain surface may be determined based on the first normal and the first reflection parameter of each contour point on the surface of the object model in the first image frame, so as to determine a function parameter of the BRDF. Those skilled in the art may adopt, according to an actual definition of the BRDF, a proper manner to determine the BRDF of the object model based on the first normal and the first reflection parameter of each contour point on the surface of the object model in the first image frame. The embodiments of this application are not limited thereto.

[00259] At S412, input lighting of the preset physical renderer is determined based on the preset first lighting image and the light visibility of each contour point on the surface of the object model in the first image frame.

[00260] Herein, by means of the light visibility of each contour point on the surface of

the object model in the first image frame, the incident light in the first lighting image may be covered to obtain the input lighting of the physical renderer.

[00261] In some implementations, the input lighting $L_i(p, w_i)$ of the physical renderer may be obtained by multiplying the light visibility $V(p, w_i)$ of each contour point P on the surface of the object model in the first image frame under the incident light w_i in the first lighting image and the lighting $L_i(w_i)$ of the incident light w_i , which may be in accordance with the following formula 8:

$$L_i(p, w_i) = V(p, w_i) L_i(w_i) \quad (8).$$

[00262] At S413, by using the physical renderer, the preset object in the first image frame is rendered based on the BRDF and the input lighting, to obtain the second image frame after relighting.

[00263] Herein, the physical renderer may adopt the appropriate rendering pipeline, and modeling is performed on the process of reflection and perception rendering, so that the preset object in the first image frame may be rendered based on the BRDF and the input lighting, to obtain the second image frame after relighting.

[00264] In some implementations, the rendering pipeline used by the physical renderer may be shown as the following formula 9:

$$L_o(p, w_o) \approx \sum_{w_i} R(p, w_i, w_o, n(p)) L_i(p, w_i) (w_i \cdot n(p)) \cdot w_i \quad (9).$$

$R(p, w_i, w_o, n(p))$ is the BRDF; $n(p)$ is the normal at the contour point P ; w_o is an emitted light; w_i is the incident light at the contour point P ; $L_i(p, w_i)$ is incident radiance that the incident light w_i reaches the contour point P ; and $L_o(p, w_o)$ is emitting radiance of the contour point P that is observed on the emitted light w_o .

[00265] In the above embodiment, the BRDF of the object model is determined based on the first normal and the first reflection parameter of each contour point on the surface

of the object model in the first image frame. The input lighting of the preset physical renderer is determined based on the preset first lighting image and the light visibility of each contour point on the surface of the object model in the first image frame. By using the physical renderer, the preset object in the first image frame is rendered based on the BRDF and the input lighting, to obtain the second image frame after relighting. In this way, the preset object in the first image frame may be rapidly and accurately rendered by using the BRDF, so that the visual effect of the relighted second image frame may be further improved.

[00266] FIG. 5 is a schematic implementation flowchart of an image processing method according to an embodiment of this application. As shown in FIG. 5, the method includes the following S501 to S503.

[00267] At S501, an image frame sequence including a preset object and an object model corresponding to the preset object are acquired.

[00268] At S502, a first geometric parameter and a first reflection parameter on a surface of the object model are determined based on the image frame sequence.

[00269] Herein, S501 to S502 respectively correspond to S101 to S102, which may refer to specific implementations of S101 to S102 during implementation.

[00270] At S503, according to a preset viewing direction, the preset object in at least one first image frame in the image frame sequence is rendered based on the preset first lighting image, the first geometric parameter, and the first reflection parameter, to obtain at least one second image frame after relighting.

[00271] Herein, the preset viewing direction may be preset according to an actual lighting requirement. During implementation, those skilled in the art may select a suitable viewing direction according to actual situations, and the embodiments of this application are not limited thereto.

[00272] In an embodiment of this application, due to the first geometric parameter and the first reflection parameter on the surface of the object model, the geometric property and the reflection feature of the surface of the object model may be embodied. Based on

the preset first lighting image and the first geometric parameter and the first reflection parameter on the surface of the object model, the free view rendering of the preset object may be supported. Therefore, a relighting requirement for the preset object may be better met, thereby improving user experience.

[00273] The application of the image processing method provided in the embodiments of this application in an actual scenario is described below by using a scenario of relighting a human body as an example.

[00274] In the image processing method provided in the embodiments of this application, a deep learning algorithm is used. A video including a target human body is recovered and estimates various parameters of the physical renderer, and the target human body is rendered and lighted again according to the first lighting image and the viewing direction that are inputted by a user. The method may be performed by a processor of a computer device.

[00275] The image processing method provided in the embodiments of this application includes the following process flow: human body parametric model estimation, human body geometric parameter estimation, human body reflection parameter estimation, and physical rendering. FIG. 6A is a schematic implementation flowchart of an image processing method according to an embodiment of this application. Implementation processes of the process flow are respectively described with reference to FIG. 6A.

[00276] 1) Human body parametric model estimation

[00277] During the implementation of human body parametric model estimation, a human body parametric model may be estimated from an inputted video I including a dynamic target human body. The target human body is expressed as a four-dimensional neural field Ψ . Each first image frame in the video I corresponds to a time point. The four-dimensional neural field Ψ may output a latent feature vector $\psi_t(p)$ (corresponding to the feature representation in the foregoing embodiments) of a human body three-dimensional coordinate point P at the time point t according to any human body three-dimensional coordinate point P and any time point t in the human body parametric model. During the estimation of the human body parametric model, a latent vector z may

be assigned for each vertex in the human body parametric model, as the feature representation of the human body three-dimensional coordinate point corresponding to each vertex at each time point.

[00278] 2) Human body geometric parameter estimation

[00279] During the implementation of human body geometric parameter estimation, by using the preset first sub-network and the second sub-network, a normal $n(p)$ and light visibility $V(p)$ of each contour point p on a surface of the human body at each time point may be predicted based on each latent feature vector $\psi_t(p)$.

[00280] 3) Human body reflection parameter estimation

[00281] During the implementation of human body reflection parameter estimation, by using the preset third sub-network and the fourth sub-network, a diffuse reflection parameter $A(p)$ and specular reflection parameter $\gamma(p)$ of each contour point on a surface of the human body at each time point may be predicted based on each latent feature vector $\psi_t(p)$.

[00282] 4) Physical rendering

[00283] The implementation of physical rendering may include S631 to S633.

[00284] At S631, the BRDF $R(\square)$ is calculated based on the normal $n(p)$, the diffuse reflection parameter $A(p)$, and the specular reflection parameter $\gamma(p)$ of each contour point P on the surface of the human body at each time point.

[00285] At S632, based on the inputted first lighting image $L_i(w_i)$, the light visibility $V(p)$ of each contour point P on the surface of the human body at each time point is used as a mask, to obtain the input lighting w_i of the physical renderer.

[00286] At S633, by using the physical renderer, the human body in the first image frame corresponding to each time point is rendered based on the BRDF and the input

lighting w_i , so that an emitted light w_o of each contour point P on the surface of the human body at each time point may be obtained. Therefore, at least one second image frame i' including the relighted human body may be obtained.

[00287] FIG. 6B is a schematic diagram of an effect of relighting a human body by using an image processing method according to an embodiment of this application. As shown in FIG. 6B, for a video I1 including the dynamic target human body, at least one first image frame in the video I1 is rendered with different input lighting images (corresponding to the first lighting images) by using the image processing method provided in the embodiments of this application, so that at least one second image frame i11, i12, or i13 after relighting may be obtained. For a video I2 including the dynamic target human body, at least one first image frame in the video I2 is rendered with different input lighting images (corresponding to the first lighting images) by using the image processing method provided in the embodiments of this application, so that at least one second image frame i21, i22, or i23 after relighting may be obtained. It is to be learned that, according to the image processing method provided in the embodiments of this application, the natural and realistic visual effect of relighting the human body can be achieved under various postures, viewing directions, and input lighting images.

[00288] According to the image processing method provided in the embodiments of this application, a set parameter and reflection parameter on the surface of the human body may be extracted from the video including the dynamic human body without professional technicians, professional modeling software, and expensive large-scale acquisition devices. Based on the extracted set parameter and the reflection parameter on the surface of the human body, the relighting of the human body at a free posture and a free viewing angle can be achieved.

[00289] The image processing method provided by the embodiments of this application is applicable to industries such as media editing, movies, and live broadcasts, or in scenarios such as virtual reality and metaverse, where users can obtain high-quality relightable human models without using a large-scale acquisition device, and render natural lighting effects according to user needs, causing the human body visual effects in applications such as background replacement, video editing, and virtual scenario live

broadcast more realistic.

[00290] Based on the foregoing embodiments, an embodiment of this application provides an image processing apparatus. The apparatus includes the included units and modules included in the units, and may be implemented by using a processor in a computer device. Definitely, the apparatus may alternatively be implemented by using a specific logic circuit. During implementation, the processor may be a Central Processing Unit (CPU), a Microprocessor Unit (MPU), a Digital Signal Processor (DSP), or a Field Programmable Gate Array (FPGA).

[00291] FIG. 7 is a schematic diagram of a composition structure of an image processing apparatus according to an embodiment of this application. As shown in FIG. 7, the image processing apparatus 700 includes an acquisition module 710, a determination module 720, and a rendering module 730.

[00292] The acquisition module 710 is configured to acquire an image frame sequence including a preset object and an object model corresponding to the preset object.

[00293] The determination module 720 is configured to determine a first geometric parameter and a first reflection parameter on a surface of the object model based on the image frame sequence.

[00294] The rendering module 730 is configured to render the preset object in at least one first image frame in the image frame sequence to obtain at least one second image frame after relighting based on a preset first lighting image, the first geometric parameter, and the first reflection parameter.

[00295] In some embodiments, the first geometric parameter on the surface of the object model includes the first geometric parameter of each contour point on the surface of the object model in each first image frame. The first reflection parameter on the surface of the object model includes the first reflection parameter of each contour point on the surface of the object model in each first image frame. The determination module is further configured to: determine a feature representation of each vertex of the object model; determine, for each first image frame in the image frame sequence, a corresponding coordinate value of each vertex in the first image frame, and determine

each contour point on the surface of the object model in the first image frame, and the coordinate value and the feature representation corresponding to each contour point based on the feature representation of each vertex and the coordinate value corresponding to the vertex in the first image frame; and determine the first geometric parameter and the first reflection parameter of each contour point based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame.

[00296] In some embodiments, the determination module is further configured to: determine at least one contour point on the surface of the object model in the first image frame and the coordinate value corresponding to each contour point based on the corresponding coordinate value of each vertex in the first image frame; determine at least one vertex adjacent to each contour point based on the coordinate value corresponding to each contour point; and determine, for each contour point, the feature representation corresponding to the contour point based on the feature representation of each vertex adjacent to the contour point.

[00297] In some embodiments, the determination module is further configured to: determine the first geometric parameter and the first reflection parameter of each contour point based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using a preset first neural network; determine a loss value based on the first geometric parameter and the first reflection parameter of each contour point on the surface of the object model in each first image frame; and update a network parameter of the first neural network and the feature representation of each vertex of the object model based on the loss value, and obtain the updated first geometric parameter and the first reflection parameter of each contour point based on the updated first neural network and the updated feature representation of each vertex.

[00298] In some embodiments, the loss value includes a first loss value. The determination module is further configured to: determine a second lighting image corresponding to the image frame sequence; for each first image frame, use the second lighting image to render the preset object in the first image frame based on the first

geometric parameter and the first reflection parameter of each contour point on the surface of the object model in the first image frame, to obtain a third image frame after relighting; and determine the first loss value based on each first image frame and each third image frame.

[00299] In some embodiments, the determination module is further configured to update the network parameter of the first neural network, the feature representation of each vertex of the object model, and the second lighting image. The determination module is further configured to: for each first image frame, use the updated second lighting image to render the preset object in the first image frame based on the updated first geometric parameter and the updated first reflection parameter of each contour point on the surface of the object model in the first image frame, to obtain the updated and relighted third image frame; and determine the updated first loss value based on each first image frame and each updated third image frame.

[00300] In some embodiments, the loss value includes a second loss value. The determination module is further configured to: determine a second geometric parameter of each contour point based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using a preset second neural network; and determine the second loss value based on the first geometric parameter and the second geometric parameter of each contour point.

[00301] In some embodiments, the determination module is further configured to: for each first image frame, determine at least one first spatial point corresponding to each contour point based on the coordinate value corresponding to each contour point on the surface of the object model in the first image frame, where the first spatial point corresponding to each contour point is a spatial point of a light source corresponding to the image frame sequence along incident light of the contour point; determine a feature representation of each first spatial point based on the feature representation of each vertex and the coordinate value corresponding to the vertex in each first image frame; determine a volume density of each first spatial point based on the feature representation of each first spatial point by using the preset second neural network; determine a second

geometric parameter of each contour point based on the volume density of at least one first spatial point corresponding to each contour point; and update the network parameter of the first neural network, a network parameter of the second neural network, and the feature representation of each vertex of the object model.

[00302] In some embodiments, the determination module is further configured to achieve at least one of the following: in a case that the second geometric parameter includes a second normal, determine a volume density gradient corresponding to each contour point in each first image frame based on the volume density of at least one first spatial point corresponding to each contour point, and determine a second normal of each contour point based on the volume density gradient corresponding to each contour point in each first image frame; or in a case that the second geometric parameter includes light visibility, for each contour point, determine cumulative transmittance of each first spatial point based on the volume density of at least first spatial point corresponding to the contour point, and determine second light visibility of the contour point based on the cumulative transmittance and the volume density of each first spatial point.

[00303] In some embodiments, the determination module is further configured to: for each camera light in at least one preset camera light, determine at least one second spatial point along the camera light; determine a feature representation of each second spatial point based on the feature representation of each vertex and the coordinate value corresponding to the vertex in each first image frame; determine a volume density corresponding to each second spatial point in the first image frame based on the feature representation of each second spatial point by using the second neural network; and for each camera light, determine the contour point on the surface of the object model based on the volume density of each second spatial point on the camera light.

[00304] In some embodiments, the first neural network includes a first prediction network and a second prediction network. The determination module is further configured to: determine the first geometric parameter of each contour point based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the preset first prediction network; and determine the first reflection parameter of each contour point

based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the preset second prediction network.

[00305] In some embodiments, the first prediction network includes a first sub-network and a second sub-network, and the first geometric parameter includes a first normal and first light visibility. The determination module is further configured to: determine a first normal of each contour point based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the first sub-network; and determine first light visibility of each contour point based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the second sub-network.

[00306] In some embodiments, the loss value further includes a third loss value. The determination module is further configured to: determine, for each first image frame, a coordinate value and a feature representation of a third spatial point corresponding to each contour point on the surface of the object model in the first image frame based on the feature representation of each vertex and the coordinate value corresponding to the vertex in the first image frame, where the third spatial point corresponding to each contour point is obtained by performing position disturbance on each contour point; determine a first normal of each third spatial point based on the coordinate value and the feature representation of the third spatial point corresponding to each contour point on the surface of the object model in each first image frame by using the first sub-network; and determine the third loss value based on the first normal of each contour point and the first normal of the third spatial point corresponding to each contour point.

[00307] In some embodiments, the loss value further includes a fourth loss value. The determination module is further configured to: determine, for each first image frame, a coordinate value and a feature representation of a fourth spatial point corresponding to each contour point on the surface of the object model in the first image frame based on the feature representation of each vertex and the coordinate value corresponding to the vertex in the first image frame, where the fourth spatial point corresponding to each

contour point is obtained by performing position disturbance on each contour point; determine first light visibility of each fourth spatial point based on the coordinate value and the feature representation of the fourth spatial point corresponding to each contour point on the surface of the object model in each first image frame by using the second sub-network; and determine the fourth loss value based on the first light visibility of each contour point and the first light visibility of the fourth spatial point corresponding to each contour point.

[00308] In some embodiments, the second prediction network includes a third sub-network and a fourth sub-network, and the first reflection parameter includes a first diffuse reflection parameter and a specular reflection parameter. The determination module is further configured to: determine a first diffuse reflection parameter of each contour point based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the third sub-network; and determine a specular reflection parameter of each contour point based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the fourth sub-network.

[00309] In some embodiments, the loss value further includes a fifth loss value. The determination module is further configured to: determine, for each first image frame, a coordinate value and a feature representation of a fifth spatial point corresponding to each contour point on the surface of the object model in the first image frame based on the feature representation of each vertex and the coordinate value corresponding to the vertex in the first image frame, where the fifth spatial point corresponding to each contour point is obtained by performing position disturbance on each contour point; determine a first diffuse reflection parameter of each fifth spatial point based on the coordinate value and the feature representation of the fifth spatial point corresponding to each contour point on the surface of the object model in each first image frame by using the third sub-network; and determine the fifth loss value based on the first diffuse reflection parameter of each contour point and the first diffuse reflection parameter of the fifth spatial point corresponding to each contour point.

[00310] In some embodiments, the first geometric parameter on the surface of the object model includes the first geometric parameter of each contour point on the surface of the object model in each first image frame, and the first reflection parameter on the surface of the object model includes the first reflection parameter of each contour point on the surface of the object model in each first image frame. The rendering module is further configured to, for each of the at least one first image frame, render, by using a preset physical renderer, the preset object in the first image frame based on the preset first lighting image, and the first geometric parameter and the first reflection parameter of each contour point on the surface of the object model in the first image frame, to obtain the second image frame after relighting.

[00311] In some embodiments, the first geometric parameter includes the first normal and the first light visibility. The rendering module is further configured to: determine a BRDF of the object model based on the first normal and the first reflection parameter of each contour point on the surface of the object model in the first image frame; determine input lighting of the preset physical renderer based on the preset first lighting image and the light visibility of each contour point on the surface of the object model in the first image frame; and render, by using the physical renderer, the preset object in the first image frame based on the BRDF and the input lighting, to obtain the second image frame after relighting.

[00312] In some embodiments, the rendering module is further configured to render, according to a preset viewing direction, the preset object in at least one first image frame in the image frame sequence based on the preset first lighting image, the first geometric parameter, and the first reflection parameter, to obtain at least one second image frame after relighting.

[00313] The descriptions of the above apparatus embodiments are similar to the descriptions of the above method embodiments, and have similar beneficial effects to the method embodiments. In some embodiments, functions or modules of the apparatus provided in the embodiments of the disclosure may be configured to execute the method described in the above method embodiment. For technical details not disclosed in the apparatus embodiments of this application, refer to the descriptions of the method

embodiments of this application for understanding.

[00314] It is to be noted that, in the embodiments of this application, if the above image processing method is implemented in the form of a software functional module and sold or used as an independent product, it can be stored in the computer-readable storage medium. Based on such an understanding, the technical solutions of the embodiments of this application substantially or parts making contributions to the related art may be embodied in form of a software product, and the software product is stored in a storage medium, including a plurality of instructions for causing a computer device (which may be a personal computer, a server, a network device or the like) to execute all or part of the method in each embodiment of the present disclosure. The foregoing storage medium includes: a USB flash disk, a mobile Hard Disk Drive (HDD), a Read-Only Memory (ROM), and various media that can store program codes, such as a magnetic disk, or an optical disk. In this way, the embodiments of this application are not limited to any specific hardware, software, or firmware, or any combination of hardware, software, and firmware.

[00315] An embodiment of this application provides a computer device. The computer device includes a memory and a processor. The memory stores a computer program executable on the processor. The processor, when executing the computer program, implements the above method.

[00316] An embodiment of the present disclosure provides a computer-readable storage medium. The computer-readable storage medium stores a computer program. The above method is implemented when the computer program is performed by a processor. The computer-readable storage medium may be transitory or non-transitory.

[00317] An embodiment of this application provides a computer program. The computer program includes a computer-readable code. When the computer-readable code is operated in a computer device, a processor in the computer device executes and implements part or all of steps is the above method.

[00318] An embodiment of this application provides a computer program product. The computer program product includes a non-transitory computer-readable storage medium

storing a computer program. When the computer program is read and executed by a computer, part or all of steps in the above method are implemented. The computer program product can be specifically implemented in a manner of hardware, software or a combination thereof. In some embodiments, the computer program product is embodied as a computer storage medium. In some other embodiments, the computer program product is embodied as a software product, such as a Software Development Kit (SDK) and the like.

[00319] Herein, it is to be noted that, the above description of the various embodiments tends to emphasize the differences between the various embodiments, and the identicalness or similarities can be referred to each other. The descriptions of the above device, storage medium, computer program, and computer program product embodiments are similar to the descriptions of the above method embodiments, and have similar beneficial effects to the method embodiments. For technical details not disclosed in the embodiments of the device, storage medium, computer program and computer program product of this application, refer to the description of the method embodiments of this application for understanding.

[00320] It is to be noted that, FIG. 8 is a schematic diagram of a hardware entity of a computer device according to an embodiment of this application. As shown in FIG. 8, a hardware entity of the computer device 800 includes a processor 801, a communication interface 802, and a memory 803.

[00321] The processor 801 usually controls an overall operation of the computer device 800.

[00322] The communication interface 802 may cause the computer device to achieve communication with other terminals or servers through a network.

[00323] The memory 803 is configured to store an instruction and an application executable by the processor 801, or may cache data to be processed or processed by the processor 801 and each module in the computer device 800 (such as, image data, audio data, voice communication data, and video communication data), which may be implemented by using FLASH or a Random Access Memory (RAM). Data transmission

among the processor 801, the communication interface 802, and the memory 803 may be achieved by using a bus 804.

[00324] It is to be understood that "one embodiment" and "an embodiment" mentioned in the whole specification mean that specific features, structures or characteristics related to the embodiment is included in at least one embodiment of this application. Therefore, "in one embodiment" or "in an embodiment" appearing at any place of the whole specification does not always refer to the same embodiment. In addition, these specific features, structures or characteristics may be combined in one or more embodiments in any proper manner. It is to be understood that, in various embodiments of this application, the sequence number of each step/process does not mean the sequence of execution. The execution sequence of each step/process should be determined by its functions and internal logic, which should not constitute any limitation on the implementation process of the embodiments of this application. The serial numbers of the foregoing embodiments of this application are merely for description, and do not represent the superiority or inferiority of the embodiments.

[00325] It is to be noted that terms "include" and "comprise" or any other variant thereof is intended to cover nonexclusive inclusions herein, so that a process, method, object or apparatus including a series of components not only includes those components but also includes other components which are not clearly listed or further includes components intrinsic to the process, the method, the object or the apparatus. Under the condition of no more limitations, a component defined by the statement "including a/an....." does not exclude existence of the same other components in a process, method, object or apparatus including the component.

[00326] In several embodiments provided by this application, it is to be understood that the disclosed device and method may be implemented in other ways. The device embodiment described above is only schematic, and for example, division of the units is only logic function division, and other division manners may be adopted during practical implementation. For example, a plurality of units or components may be combined or integrated into another system, or some characteristics may be neglected or not executed. In addition, coupling or direct coupling or communication connection between each

displayed or discussed component may be indirect coupling or communication connection, implemented through some interfaces, of the device or the units, and may be electrical and mechanical or adopt other forms.

[00327] The units described as separate parts may or may not be physically separated, and parts displayed as units may or may not be physical units, and namely may be located in the same place, or may also be distributed to multiple network units. Part of all of the units may be selected according to a practical requirement to achieve the purposes of the solutions of the embodiments.

[00328] In addition, each functional unit in each embodiment of this application may be integrated into a processing unit, each unit may also serve as an independent unit and two or more than two units may also be integrated into a unit. The integrated unit may be implemented in a hardware form and may also be implemented in form of hardware and software functional unit.

[00329] Those of ordinary skill in the art should know that all or part of the steps of the method embodiment may be implemented by related hardware instructed through a program, the program may be stored in a computer-readable storage medium, and the program is executed to execute the steps of the method embodiment. The storage medium which may be a volatile storage medium includes: a mobile storage device, an ROM, and various media that can store program codes, such as a magnetic disk, or an optical disk.

[00330] Or, if the integrated unit is implemented in the form of the software functional unit and sold or used as an independent product, it can be stored in the computer readable storage medium. Based on such an understanding, the technical solutions of this application substantially or parts making contributions to the related art may be embodied in form of a software product, and the computer software product is stored in a storage medium, including a plurality of instructions for causing a computer device (which may be a personal computer, a server, a network device or the like) to execute all or part of the method in each embodiment of this application. The foregoing storage medium includes a portable storage device, an ROM, and various media that can store program codes, such as a magnetic disk, or an optical disk.

[00331] The above is only the implementations of this application and not intended to limit the scope of protection of this application. Any variations or replacements apparent to those skilled in the art within the technical scope disclosed by this application shall fall within the scope of protection of this application.

CLAIMS

1. An image processing method, comprising:

acquiring an image frame sequence comprising a preset object and an object model corresponding to the preset object;

determining a first geometric parameter and a first reflection parameter on a surface of the object model based on the image frame sequence; and

rendering the preset object in at least one first image frame in the image frame sequence based on a preset first lighting image, the first geometric parameter, and the first reflection parameter, to obtain at least one second image frame after relighting.

2. The method of claim 1, wherein the first geometric parameter on the surface of the object model comprises the first geometric parameter of each contour point on the surface of the object model in each first image frame, and the first reflection parameter on the surface of the object model comprises the first reflection parameter of each contour point on the surface of the object model in each first image frame;

wherein the determining a first geometric parameter and a first reflection parameter on a surface of the object model based on the image frame sequence comprises:

determining a feature representation of each vertex of the object model;

for the each first image frame in the image frame sequence, determining a corresponding coordinate value of each vertex in the first image frame, and determining each contour point on the surface of the object model in the first image frame, and the coordinate value and the feature representation corresponding to each contour point based on the feature representation of each vertex and the coordinate value corresponding to the vertex in the first image frame; and

determining the first geometric parameter and the first reflection parameter of each

contour point based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame.

3. The method of claim 2, wherein the determining each contour point on the surface of the object model in the first image frame, and the coordinate value and the feature representation corresponding to each contour point based on the feature representation of each vertex and the coordinate value corresponding to the vertex in the first image frame comprises:

determining at least one contour point on the surface of the object model in the first image frame and the coordinate value corresponding to each contour point based on the corresponding coordinate value of each vertex in the first image frame;

determining at least one vertex adjacent to each contour point based on the coordinate value corresponding to each contour point; and

for each contour point, determining the feature representation corresponding to the contour point based on the feature representation of each vertex adjacent to the contour point.

4. The method of claim 2 or 3, wherein the determining the first geometric parameter and the first reflection parameter of each contour point based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame comprises:

determining the first geometric parameter and the first reflection parameter of each contour point based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using a preset first neural network;

determining a loss value based on the first geometric parameter and the first reflection parameter of each contour point on the surface of the object model in each first image frame; and

updating a network parameter of the first neural network and the feature representation

of each vertex of the object model based on the loss value, and obtaining an updated first geometric parameter and an updated first reflection parameter of each contour point based on an updated first neural network and an updated feature representation of each vertex.

5. The method of claim 4, wherein the loss value comprises a first loss value;

wherein the determining a loss value based on the first geometric parameter and the first reflection parameter of each contour point on the surface of the object model in each first image frame comprises:

determining a second lighting image corresponding to the image frame sequence;

for each first image frame, rendering the preset object in the first image frame based on the first geometric parameter and the first reflection parameter of each contour point on the surface of the object model in the first image frame by using the second lighting image, to obtain a third image frame after relighting; and

determining the first loss value based on each first image frame and each third image frame.

6. The method of claim 5, wherein the updating a network parameter of the first neural network and the feature representation of each vertex of the object model comprises:

updating the network parameter of the first neural network, the feature representation of each vertex of the object model, and the second lighting image;

wherein the determining the first geometric parameter and the first reflection parameter of each contour point based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame further comprises:

for each first image frame, rendering the preset object in the first image frame based on the updated first geometric parameter and the updated first reflection parameter of each

contour point on the surface of the object model in the first image frame by using the updated second lighting image, to obtain the updated and relighted third image frame; and

determining the updated first loss value based on each first image frame and each updated third image frame.

7. The method of claim 5 or 6, wherein the loss value further comprises a second loss value;

wherein the determining a loss value based on the first geometric parameter and the first reflection parameter of each contour point on the surface of the object model in each first image frame further comprises:

determining a second geometric parameter of each contour point based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using a preset second neural network; and

determining the second loss value based on the first geometric parameter and the second geometric parameter of each contour point.

8. The method of claim 7, wherein the determining a second geometric parameter of each contour point based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using a preset second neural network comprises:

for each first image frame, determining at least one first spatial point corresponding to each contour point based on the coordinate value corresponding to each contour point on the surface of the object model in the first image frame, wherein the first spatial point corresponding to each contour point is a spatial point of a light source corresponding to the image frame sequence along incident light of the contour point;

determining a feature representation of each first spatial point based on the feature representation of each vertex and the coordinate value corresponding to the vertex in each

first image frame;

determining a volume density of each first spatial point based on the feature representation of each first spatial point by using the preset second neural network; and

determining a second geometric parameter of each contour point based on the volume density of at least one first spatial point corresponding to each contour point;

wherein the updating a network parameter of the first neural network and the feature representation of each vertex of the object model comprises:

updating the network parameter of the first neural network, a network parameter of the second neural network, and the feature representation of each vertex of the object model.

9. The method of claim 8, wherein the determining a second geometric parameter of each contour point based on the volume density of at least one first spatial point corresponding to each contour point comprises at one of:

in a case that the second geometric parameter comprises a second normal, determining a volume density gradient corresponding to each contour point in each first image frame based on the volume density of at least one first spatial point corresponding to each contour point, and determining a second normal of each contour point based on the volume density gradient corresponding to each contour point in each first image frame; or

in a case that the second geometric parameter comprises light visibility, for each contour point, determining cumulative transmittance of each first spatial point based on the volume density of at least first spatial point corresponding to the contour point, and determining second light visibility of the contour point based on the cumulative transmittance and the volume density of each first spatial point.

10. The method of claim 8 or 9, wherein the determining each contour point on the surface of the object model in the first image frame based on the feature representation of each vertex and the coordinate value corresponding to the vertex in the first image frame comprises:

for each camera light in at least one preset camera light, determining at least one second spatial point along the camera light;

determining a feature representation of each second spatial point based on the feature representation of each vertex and the coordinate value corresponding to the vertex in each first image frame;

determining a volume density corresponding to each second spatial point in the first image frame based on the feature representation of each second spatial point by using the second neural network; and

for each camera light, determining the contour point on the surface of the object model based on the volume density of each second spatial point on the camera light.

11. The method of any of claims 7 to 10, wherein the first neural network comprises a first prediction network and a second prediction network;

wherein the determining the first geometric parameter and the first reflection parameter of each contour point based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using a preset first neural network comprises:

determining the first geometric parameter of each contour point based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the preset first prediction network; and

determining the first reflection parameter of each contour point based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the preset second prediction network.

12. The method of claim 11, wherein the first prediction network comprises a first sub-

network and a second sub-network; the first geometric parameter comprises a first normal and first light visibility;

wherein the determining the first geometric parameter of each contour point based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the preset first prediction network comprises:

determining a first normal of each contour point based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the first sub-network; and

determining first light visibility of each contour point based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the second sub-network.

13. The method of claim 12, wherein the loss value further comprises a third loss value;

wherein the determining a loss value based on the first geometric parameter and the first reflection parameter of each contour point on the surface of the object model in each first image frame further comprises:

for each first image frame, determining a coordinate value and a feature representation of a third spatial point corresponding to each contour point on the surface of the object model in the first image frame based on the feature representation of each vertex and the coordinate value corresponding to the vertex in the first image frame, wherein the third spatial point corresponding to each contour point is obtained by performing position disturbance on each contour point;

determining a first normal of each third spatial point based on the coordinate value and the feature representation of the third spatial point corresponding to each contour point on the surface of the object model in each first image frame by using the first sub-network; and

determining the third loss value based on the first normal of each contour point and

the first normal of the third spatial point corresponding to each contour point.

14. The method of claim 12 or 13, wherein the loss value further comprises a fourth loss value; wherein the determining a loss value based on the first geometric parameter and the first reflection parameter of each contour point on the surface of the object model in each first image frame further comprises:

for each first image frame, determining a coordinate value and a feature representation of a fourth spatial point corresponding to each contour point on the surface of the object model in the first image frame based on the feature representation of each vertex and the coordinate value corresponding to the vertex in the first image frame, wherein the fourth spatial point corresponding to each contour point is obtained by performing position disturbance on each contour point;

determining first light visibility of each fourth spatial point based on the coordinate value and the feature representation of the fourth spatial point corresponding to each contour point on the surface of the object model in each first image frame by using the second sub-network; and

determining the fourth loss value based on the first light visibility of each contour point and the first light visibility of the fourth spatial point corresponding to each contour point.

15. The method of any of claims 11 to 14, wherein the second prediction network comprises a third sub-network and a fourth sub-network; the first reflection parameter comprises a first diffuse reflection parameter and a specular reflection parameter;

wherein the determining the first reflection parameter of each contour point based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the preset second prediction network comprises:

determining a first diffuse reflection parameter of each contour point based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the third sub-network; and

determining a specular reflection parameter of each contour point based on the coordinate value and the feature representation corresponding to each contour point on the surface of the object model in each first image frame by using the fourth sub-network;

wherein the loss value further comprises a fifth loss value;

wherein the determining a loss value based on the first geometric parameter and the first reflection parameter of each contour point on the surface of the object model in each first image frame further comprises:

for each first image frame, determining a coordinate value and a feature representation of a fifth spatial point corresponding to each contour point on the surface of the object model in the first image frame based on the feature representation of each vertex and the coordinate value corresponding to the vertex in the first image frame, wherein the fifth spatial point corresponding to each contour point is obtained by performing position disturbance on each contour point;

determining a first diffuse reflection parameter of each fifth spatial point based on the coordinate value and the feature representation of the fifth spatial point corresponding to each contour point on the surface of the object model in each first image frame by using the third sub-network; and

determining the fifth loss value based on the first diffuse reflection parameter of each contour point and the first diffuse reflection parameter of the fifth spatial point corresponding to each contour point.

16. The method of any of claims 1 to 15, wherein the first geometric parameter on the surface of the object model comprises the first geometric parameter of each contour point on the surface of the object model in each first image frame, and the first reflection parameter on the surface of the object model comprises the first reflection parameter of each contour point on

the surface of the object model in each first image frame;

wherein the rendering the preset object in at least one first image frame in the image frame sequence based on a preset first lighting image, the first geometric parameter, and the first reflection parameter, to obtain at least one second image frame after relighting comprises:

for each of the at least one first image frame, rendering, by using a preset physical renderer, the preset object in the first image frame based on the preset first lighting image, and the first geometric parameter and the first reflection parameter of each contour point on the surface of the object model in the first image frame, to obtain the second image frame after relighting;

wherein the first geometric parameter comprises the first normal and the first light visibility;

wherein the rendering, by using a preset physical renderer, the preset object in the first image frame based on the preset first lighting image, and the first geometric parameter and the first reflection parameter of each contour point on the surface of the object model in the first image frame, to obtain the second image frame after relighting comprises:

determining a Bidirectional Reflectance Distribution Function (BRDF) of the object model based on the first normal and the first reflection parameter of each contour point on the surface of the object model in the first image frame;

determining input lighting of the preset physical renderer based on the preset first lighting image and the light visibility of each contour point on the surface of the object model in the first image frame; and

rendering, by using the physical renderer, the preset object in the first image frame, to obtain the second image frame after relighting based on the BRDF and the input lighting.

17. The method of any of claims 1 to 16, wherein the rendering the preset object in at least one first image frame in the image frame sequence based on a preset first lighting image, the first geometric parameter, and the first reflection parameter, to obtain at least one second image frame after relighting comprises:

rendering, according to a preset viewing direction, the preset object in at least one first image frame in the image frame sequence based on the preset first lighting image, the first geometric parameter, and the first reflection parameter, to obtain at least one second image frame after relighting.

18. A computer device, comprising a memory and a processing, wherein the memory stores a computer program executable on the processor, and the processor, when executing the program, implements following steps:

acquiring an image frame sequence comprising a preset object and an object model corresponding to the preset object;

determining a first geometric parameter and a first reflection parameter on a surface of the object model based on the image frame sequence; and

rendering the preset object in at least one first image frame in the image frame sequence based on a preset first lighting image, the first geometric parameter, and the first reflection parameter, to obtain at least one second image frame after relighting.

19. A computer-readable storage medium, having a computer program stored thereon, wherein the computer program, when executed by a processor, implements following steps:

acquiring an image frame sequence comprising a preset object and an object model corresponding to the preset object;

determining a first geometric parameter and a first reflection parameter on a surface of the object model based on the image frame sequence; and

rendering the preset object in at least one first image frame in the image frame sequence based on a preset first lighting image, the first geometric parameter, and the first reflection parameter, to obtain at least one second image frame after relighting.

20. A computer program, stored in a storage medium, wherein the computer program, when executed by a processor, implements following steps:

acquiring an image frame sequence comprising a preset object and an object model corresponding to the preset object;

determining a first geometric parameter and a first reflection parameter on a surface of the object model based on the image frame sequence; and

rendering the preset object in at least one first image frame in the image frame sequence based on a preset first lighting image, the first geometric parameter, and the first reflection parameter, to obtain at least one second image frame after relighting.