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(54) **METHOD FOR DESIGNING A DENTAL RESTORATION**

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(57) **ABSTRACT**

The present invention relates to a method for designing a dental restoration, comprising the steps of determining (S**101**) a target data set based on a natural tooth which reflects the optical properties and/or the geometry of the natural tooth; generating (S**102**) a digital tooth model with an internal architecture; rendering (S**103**) the digital tooth model based on the internal architecture to generate an actual data set representing the optical properties and/or the geometry of the digital tooth model; calculating (S**104**) a deviation between the target data set and the actual data set; and iteratively altering (S**105**) the digital tooth model to obtain a smaller deviation between the detected target data set and the actual data set of the re-rendered digital tooth model.

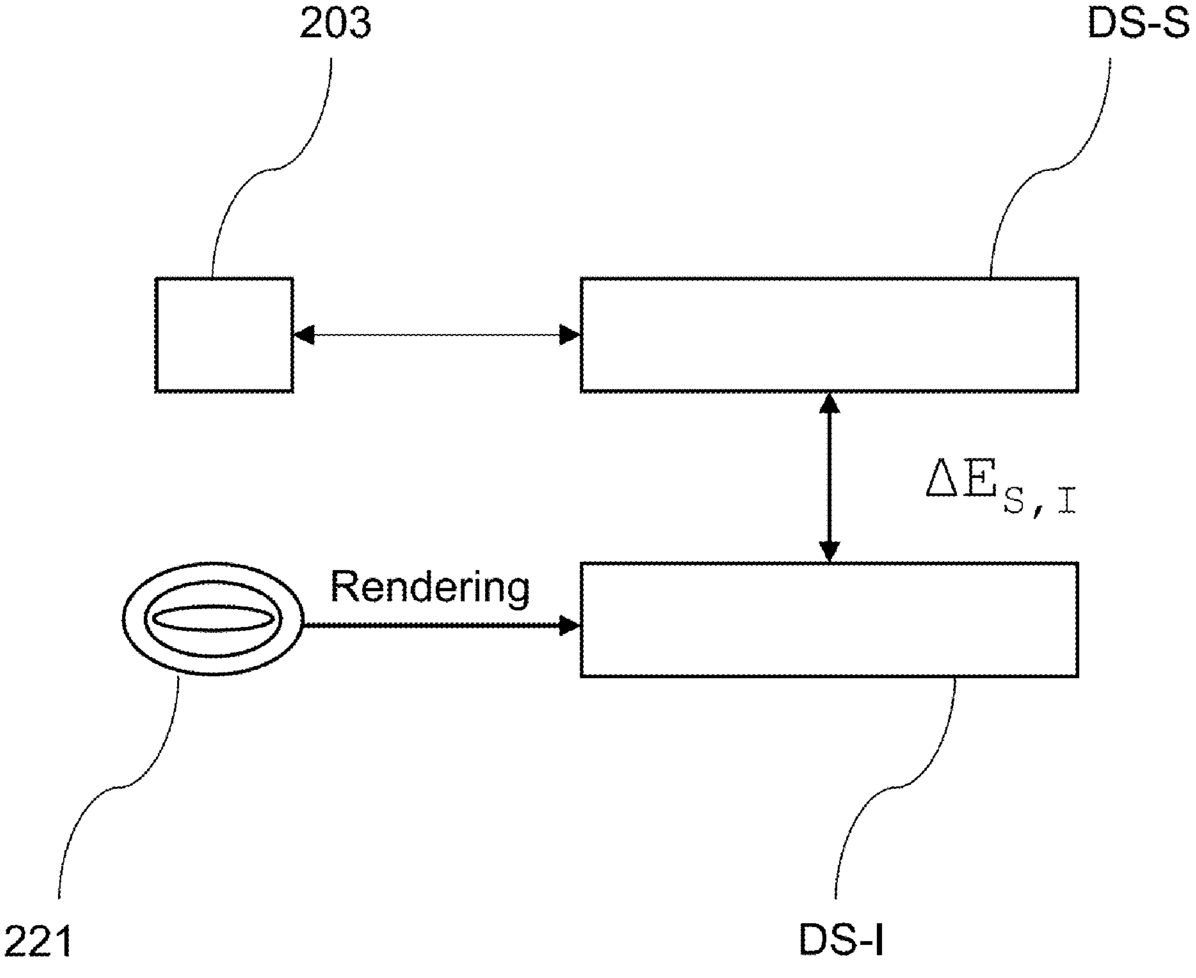


Fig. 1

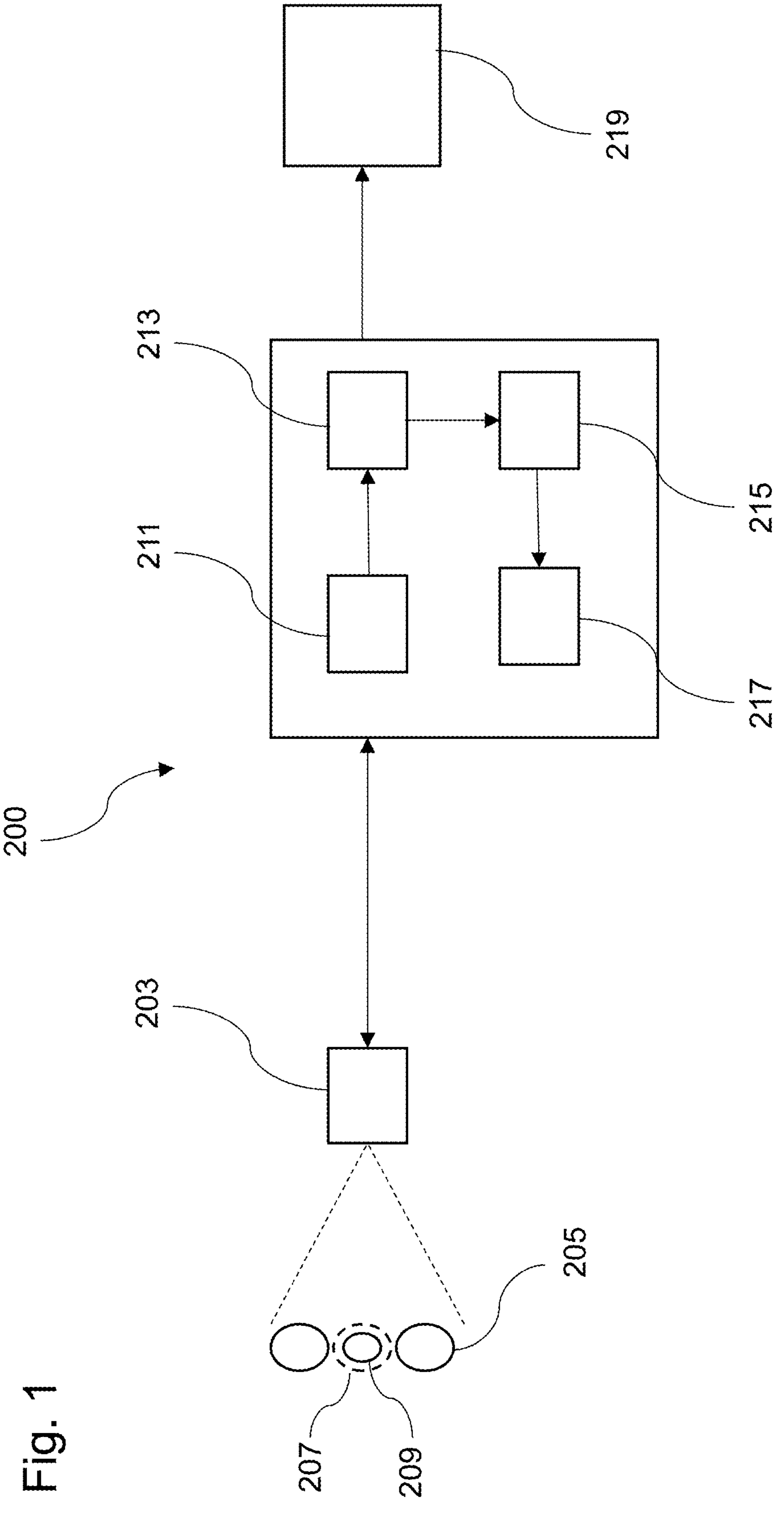


Fig. 2

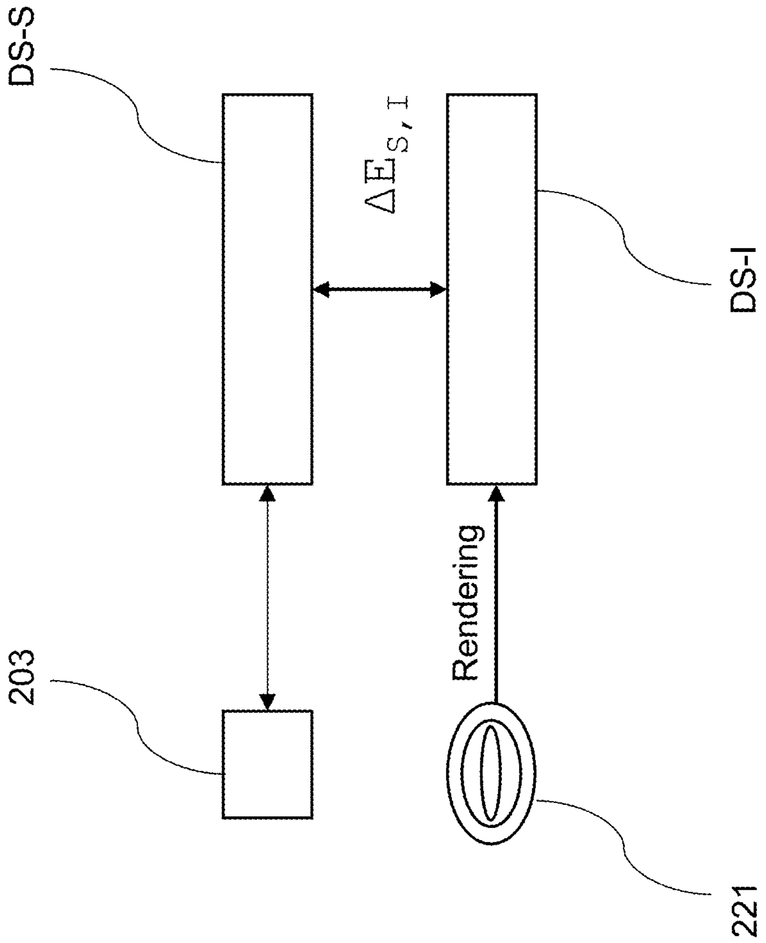
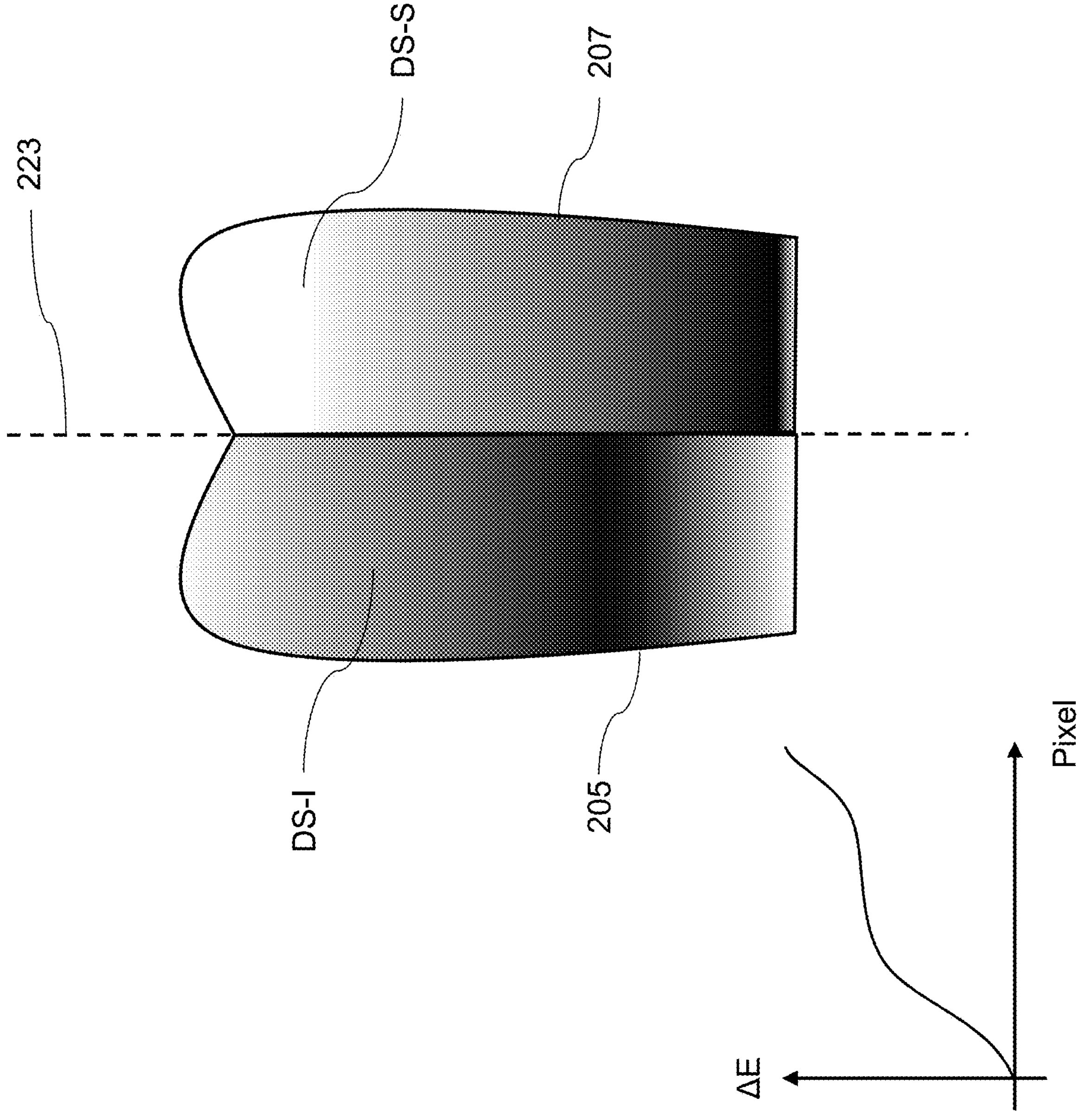


Fig. 3



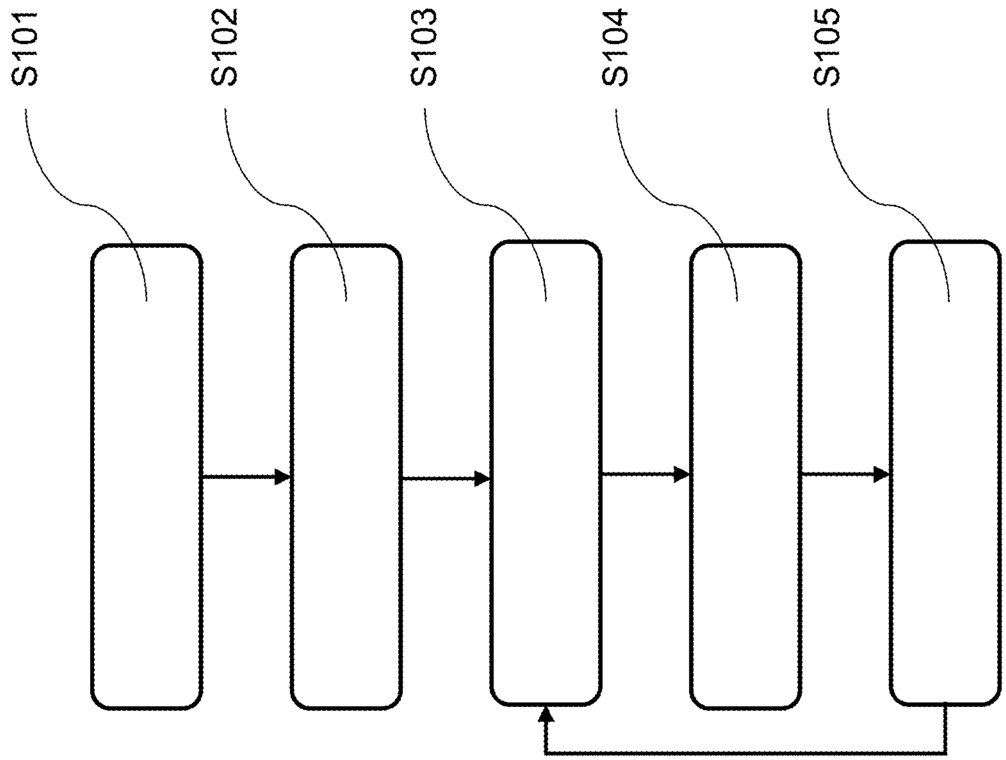


Fig. 4

METHOD FOR DESIGNING A DENTAL RESTORATION

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to European Patent Application No. 20201553.3 filed on Oct. 13, 2020, European Patent Application No. 20215945.5, filed on Dec. 21, 2020, European Patent Application No. 20215936.4, filed on Dec. 21, 2020, and European Patent Application No. 20215943.0, filed on Dec. 21, 2020, all the disclosures of which are incorporated herein by reference in their entirety.

TECHNICAL FIELD

[0002] The present invention relates to a method for designing a dental restoration, a computer device for designing a dental restoration and a computer program for the computer device.

BACKGROUND

[0003] In the fabrication of dental restorations, there are often problems with shade nuances and translucency, as these are difficult to determine and the structure of the restoration through different layers and materials has an influence on the final appearance. At present, shade determination is also often based on the experience of dental technicians or on an estimate based on a subjective shade comparison with a shade guide. Increasingly, dental restorations, especially single-tooth restorations, are also being fabricated by dentists today. Since in some cases the patient is waiting for the restoration in the dental office, an exact selection of the shade is important during fabrication.

[0004] For example, EP 2 486 892 B1 and corresponding U.S. Pat. No. 9,662,188B2, which US patent is hereby incorporated by reference, describe how a virtual tooth's appearance on a calibrated screen is compared with the image of the neighboring tooth by a user to gain a realistic impression. If the result is not yet satisfactory, the layer thickness or translucency can be adjusted, for example. However, inaccuracies always occur when a user visually compares the results on the screen.

SUMMARY

[0005] It is the technical aim of the present invention to produce a dental restoration with a more natural appearance and higher color and geometric accuracy.

[0006] This problem is solved by subject-matter according to the independent claims. Technically advantageous embodiments are the subject of the dependent claims, description, and drawings.

[0007] According to a first aspect, the technical problem is solved by a method for designing a dental restoration, comprising the steps of determining a target data set based on a natural tooth, which represents the optical properties and/or the geometry of the natural tooth; generating a digital tooth model with an internal architecture; rendering the digital tooth model based on the internal architecture to generate an actual data set representing the optical properties and/or the geometry of the digital tooth model; calculating a deviation between the target data set and the actual data set; and iteratively altering the digital tooth model to obtain a smaller deviation between the determined target data set and the actual data set of the re-rendered digital tooth model.

[0008] The internal architecture includes the spatial structure and the materials used for this structure. Since the optical properties of the materials used and the spatial structure are known, an actual data set can be rendered from the digital tooth model, which indicates the optical appearance of the digital tooth model. By automatically calculating a deviation between the target data set and the actual data set and, derived from this, adjusting the internal architecture and the materials used, the dental restoration can be produced with an appearance that corresponds to that of the natural tooth that was captured. After insertion of the dental restoration part, the artificial tooth integrates harmoniously in a variety of light situations and cannot be distinguished from the surrounding natural teeth. Depending on the materials used, the layering of the dental restoration can be realistically simulated prior to fabrication so that the user receives exactly the result he expects.

[0009] Optical parameters of the materials used are considered for rendering, which cannot be displayed and recognized on a screen on displayed images. It is also possible to consider certain material properties, the influence of adjacent teeth, gums and/or different light situations. The method is therefore independent of human perception. The digital tooth model can be altered, for example, by replacing the materials with different optical properties or by changing the arrangement or layer thickness of the materials in the internal architecture.

[0010] In a technically advantageous embodiment of the method, the deviation is calculated based on a Euclidean distance between the target data set and the actual data set. This has the technical advantage, for example, that an exact deviation measure can be determined with little effort. If the values of the target data set are available in special color values, such as Lab values, and not as tooth colors of a tooth shade guide, the comparison can be performed with high precision on the basis of a comparison of the Lab actual values with the Lab target values.

[0011] In a further technically advantageous embodiment of the method, the deviation is calculated based on a spectral distance between the target data set and the actual data set. This has the technical advantage, for example, that an exact color match between the target data set and the actual data set is achieved.

[0012] In a further technically advantageous embodiment of the method, the target data set comprises data on a two-dimensional or three-dimensional image of the natural tooth, data on an exposure angle to the tooth, data on color information of the tooth, data on a color spectrum of the tooth and/or data on geometry information of the tooth. This has the technical advantage, for example, that particularly suitable data can be used for reconstruction and calculation of the deviation.

[0013] In a further technically advantageous embodiment of the method, the target data set is captured by a digital camera, a 3D scanner, a 3D camera system, a spectrometer, or a digitized color key. This has the technical advantage, for example, that the target data set can be obtained easily and quickly without having to consider the environmental conditions, since these can then be calculated by the computer program.

[0014] In a further technically advantageous embodiment of the method, the target data set includes optical properties of a residual tooth. The data of the residual tooth can also be determined in this case. The data also include the optical properties and/or the geometry of the residual tooth. This has the technical advantage, for example, of obtaining a precise and accurate fit of the dental restoration based on the remaining tooth substance.

[0015] In a further technically advantageous embodiment of the method, the digital tooth model is rendered on the basis of the optical properties of the residual tooth, the geometry of the residual tooth, the surrounding neighboring teeth, the oral situation, the consideration of the gingiva or gingival color and/or the adhesive material used to fix the dental restoration to the residual tooth. The rendering is performed in conjunction with the optical properties of the dental restoration. This also has the technical advantage, for example, of obtaining a precise and accurate fit of the dental restoration based on the remaining tooth substance.

[0016] In a further technically advantageous embodiment of the method, the step of generating the digital tooth model comprises the step of importing, calculating and/or defining a tooth model with a given internal architecture. The step of importing can be preceded by the step of generating. This has the technical advantage, for example, that the method is accelerated and can be selected from several existing digital tooth models.

[0017] In a further technically advantageous embodiment of the method, the digital tooth model is rendered at an angle that corresponds to the angle at which the tooth was captured and/or a given lighting situation. This has the technical advantage, for example, that a better comparison can be made between the actual data set and the target data set, and the computing effort required to render the dental restoration on the residual tooth or the preparation to the corresponding perspective is reduced and thus accelerated.

[0018] In a further technically advantageous embodiment of the method, the digital tooth model is altered by changing a material assignment to a sub-volume. This has the technical advantage, for example, that larger deviations can be compensated and thus a natural structure and appearance of the dental restoration is achieved.

[0019] In a further technically advantageous embodiment of the method, the digital tooth model is altered by changing the sub-volumes while retaining the outer geometry. This also has the technical advantage, for example, that smaller deviations can be compensated without changing the materials, thus achieving a natural structure and appearance of the dental restoration.

[0020] In a further technically advantageous embodiment of the method, a balance between functional requirements, such as specified minimum wall thicknesses and aesthetic requirements, is determined, and optionally suggested to the user for evaluation.

[0021] In a further technically advantageous embodiment of the method, the dental restoration is fabricated based on the actual data set. This also has the technical advantage, for example, that the dental restoration can be produced automatically, and the previous simulation provides a correct color reproduction that corresponds to the target data set.

[0022] In a further technically advantageous embodiment of the method, the dental restoration is produced using a multi-material 3D printing device or a milling device. The fabrication of the dental restoration may also include the steps of printing the dental restoration in a stereolithography process and subsequent sintering. When using the press technique with color gradient ingots, the orientation and position of the restoration in the ingot can be individually and specifically determined. The latter two manufacturing processes, for example, provide the technical advantages of quickly producing a dental restoration with a natural appearance.

[0023] In a further technically advantageous embodiment of the method, the dental restoration is manufactured using an additive manufacturing process from multiple or selectively colored materials. The fabrication of the dental restoration can be implemented by the steps of an additive manufacturing process in which multiple materials are assigned to the predetermined sub-volumes of the dental restoration, selectively applied in space, or monochromatic materials are applied in layers, wherein individual layers are selectively colored or discolored. These additive manufacturing processes provide the technical advantages, for example, that the dental restoration can be quickly produced with a natural appearance according to the specifications of the digital target data set.

[0024] According to a second aspect, the technical problem is solved by a computer device for designing a dental restoration, with a sensor for capturing a target data set based on a natural tooth, which is suitable to perform the method according to the first aspect. In this way the same technical advantages are achieved as by the method according to the first aspect. The computer device may include a computing unit with at least one algorithm that is configured to perform the method herein.

[0025] According to a third aspect, the technical problem is solved by a computer program that includes instructions that cause the computer device according to the second aspect to perform the process steps according to the first aspect. The computer program product may include program code which is stored on a non-transitory machine-readable medium, the machine-readable medium including computer instructions executable by a processor, which computer instructions cause the processor to perform the method herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] Execution examples of the invention are shown in the drawings and are described in more detail below.

[0027] FIG. **1** a schematic view of a computer device for designing a dental restoration;

[0028] FIG. **2** a schematic representation of a deviation between a target data set and an actual data set;

[0029] FIG. **3** a schematic representation for the calculation of a deviation between a target data set and an actual data set; and

[0030] FIG. **4** a block diagram of a method for designing a dental restoration.

DETAILED DESCRIPTION

[0031] FIG. **1** shows a schematic view of a computer device **200** for designing a dental restoration **207**. The computer device **200** comprises a sensor **203** for determining a target data set based on a natural tooth **205**. The sensor **203** is capable of determining data on an acquisition angle to tooth **205**, data on shade information of tooth **205**, data on a shade spectrum of tooth **205**, data on a translucency of tooth **205** and/or data on geometry information of tooth **205**. Sensor **203** supplies the data which are embedded in a target data set for later calculation.

[0032] The sensor **203** is, for example, an electronic digital camera, a 3D scanner with color capture or a TOF camera that can measure distances using a time-of-flight (TOF) method or a camera that can measure distances using stripe light and triangulation. The **203** sensor captures the shade and geometry information of tooth **205**, such as shade distribution, translucency and/or shape of tooth **205**. The sensor **203** for shade capture may be different from the one used for geometry capture. For example, the shade can be taken by a camera and the geometry can be determined by a separate scanner. However, an analog impression can also be generated, which is then digitized using a Lab scanner.

[0033] In general, any device that is suitable for capturing shade, translucency and/or geometry information of tooth **205**, which serves as the later basis for the target data set, can be used as sensor **203**.

[0034] For example, the sensor **203** can be used to determine the geometry and shade information based on an adjacent tooth **205**, which then serves as a template for fabricating the adjacent dental restoration **207**. In addition, the sensor **203** can be designed to determine an acquisition angle of the perspective in relation to tooth **205**. The sensor **203** can be part of a mobile device, such as a smart phone or tablet. The sensor **203** can be used to perform a shade measurement or translucency measurement of the neighboring teeth **207**, for example, based on the eight natural color spaces. In addition, Sensor **203** can be used to detect the optical properties and geometry of a residual tooth **209**, such as a tooth stump, on which the dental restoration **207** is to be placed.

[0035] The computer device **200** also includes a generation unit **211** for generating a digital tooth model with an internal architecture. The internal architecture reflects an internal structure of the digital tooth model. The internal architecture may include a composition of at least two dental restorative materials with different optical and/or physical properties.

[0036] These different dental restorative materials can be arranged in voxels in the case of additive manufacturing processes or in layers in the case of a graduated material. For monochromatic materials, the layers can be selectively colored. The internal architecture of the tooth model includes not only three-dimensional information, but also information about the physical-optical properties of the restorative materials, such as an absorption coefficient or a scattering coefficient of the materials used.

[0037] The digital tooth model can be constructed from an architecture with different sub-volumes (shells), to which the respective optical and/or physical material characteristics are assigned. For this purpose, the materials and semi-finished products used are optically characterized and parameterized in advance.

[0038] For example, the generation unit **211** can be used to model both the external shape of the digital tooth model and the internal architecture in a CAD process. The digital tooth model of the tooth to be replaced can initially be imported from a digital tooth library as a three-dimensional tooth model with predefined internal architecture and then adapted to the given patient situation. The three-dimensional tooth model is based on an idealized three-dimensional structure in which the appearance is already known, i.e. has already been precalculated. By automatically assigning the target data set to a defined color space, the system makes a preselection for a material combination for the actual data set of the restoration and suggests it to the user.

[0039] The computer device **200** also has a rendering unit **213**, which optically simulates the optical appearance, i.e. the actual situation, of the biomimetic dental prosthesis based on the generated digital tooth model. During the simulation, not only the internal architecture of the tooth, but also the optical properties of the materials used and, if necessary, the mechanical properties are considered.

[0040] For this purpose, in addition to the three-dimensional geometry information, the optical parameters and/or physical properties for all layers or sub-volumes of different materials of the digital tooth model are imported into the simulation software of the rendering unit **213**. The rendering of the digital tooth model can also be performed taking into account the optical properties of a residual tooth **205** and the adhesive material used to fix the dental restoration **207**, the neighboring teeth, the gum color and/or the oral situation.

[0041] If the acquisition angle of the target data set is known, the rendering of the digital tooth model can be performed from a perspective that corresponds to that of the determined image. In this way, a two-dimensional image of the rendered digital tooth model can be generated as an actual data set from the perspective that corresponds to the perspective when the target data set was determined. By superimposing the two-dimensional images of the target and actual data set with the same perspective, a deviation between the target and actual data set can be calculated.

[0042] The rendering simulates the optical appearance of the dental restoration **207**, if necessary taking into account the residual tooth and adhesive material, and generates an actual data set which includes the same parameters as the target data set in order to be able to calculate a deviation.

[0043] In addition, the computer device **200** has a calculation unit **215**, which calculates a numerical deviation $\Delta E_{S,I}$ between the target data set and the actual data set. The deviation $\Delta E_{S,I}$ gives a value that quantifies the difference between the target data set and the actual data set. For example, a map matching of the actual data set with the color and translucency scheme of the target data set can be performed, so that the deviation $\Delta E_{S,I}$ is obtained from a difference image.

[0044] The deviation $\Delta E_{S,I}$ can be calculated based on a Euclidean distance or a spectral distance between the target data set and the actual data set.

[0045] In addition, the computer device **200** includes an altering unit **217** for automatically and iteratively altering the digital tooth model to obtain a smaller deviation $\Delta E_{S,I}$ between the determined target data set and the actual data set of the re-rendered digital tooth model. For this purpose, the altering unit **217** can, for example, autonomously change a layer thickness or material assignment of the tooth model so that the optical properties approach the target data set so that the real appearance is obtained.

[0046] For example, the digital tooth model is iteratively altered by changing the material allocation to the sub-volumes while retaining the outer geometry of the tooth, for example between an incisal and dentine area. The materials and optical parameters are assigned to an altered three-dimensional tooth model including preparation and cement layer and rendered again, the result is compared with the target data set and a deviation $\Delta E_{S,I}$ between the actual data set and the target data set is calculated. The dental materials that can be used can be available in an entire color palette and different translucency levels.

[0047] An actual data set is rendered again from the altered tooth model and a deviation $\Delta E_{S,I}$ between the actual data set and the target data set is calculated.

[0048] If the calculated deviation $\Delta E_{S,I}$, for example, is above a specified value, the material or material combination for the dental restoration **207** can be adapted while retaining the external shape. If the calculated deviation $\Delta E_{S,I}$ is below a specified value, fine tuning is performed by varying the sub-volumes of the internal architecture or by topographically altering the interface between the incisal and dentin while retaining the external geometry.

[0049] If a specified lower value for the deviation $\Delta E_{S,I}$ is reached, the design of restoration **207** and the material selection of the digital tooth model are completed so that the dental restoration **207** can be fabricated. If the deviation $\Delta E_{S,I}$ is below the specified value, the digital tooth model thus describes the final dental restoration **207**.

[0050] Instead of working with limit values, the two fitting methods of material fitting and interface fitting can also be used equally side by side.

[0051] This can be produced using 3D printing with multiple materials or by milling from a blank using an automated manufacturing device **219**. Once the dental restoration **207** is placed in the patient's mouth, the visual appearance of the biomimetic prosthesis is optimally approximated to the natural appearance.

[0052] The computerized device **200** allows the dental restoration **207** to be fabricated as lifelike (biomimetic) as possible and to be optically integrated as well as possible into the patient's oral environment.

[0053] The color and aesthetic assessment and selection for the materials and colors used is not subjective but can be objectively repeated by the user through a calibrated automatic process that always follows the same rules. The optical interplay of the materials used, preparation, cement layer, dentine and incisal area and the oral situation (red-white esthetics) can be realistically simulated and rendered, since the optical parameters of the materials used are clearly defined.

[0054] This enables a target/actual comparison with which the internal structure or internal architecture of the dental restoration **207** can be iteratively adapted. The user can be given corresponding colors, materials, semi-finished products and/or manufacturing processes by rendering to achieve an esthetically optimal, biomimetic result for the dental restoration **207**. In this way, a dental restoration **207** is obtained which fits optimally into the existing oral situation of the patient. The fabricated and applied dental restoration **207** is esthetically optimally integrated into the overall appearance without the subjective experience of a user who selects the material or semi-finished product according to a shade guide. Experiential knowledge can be considered or integrated in software so that even inexperienced dental technicians can benefit from it. This concerns, for example, the design of the inner architecture of the tooth or a staining technique. It could also enable the user to offer personal preferences for selection (e.g. painted according to a specified scheme) or to take demographic differences into account (gloss level).

[0055] FIG. **2** shows a schematic representation of a deviation $\Delta E_{S,I}$ between the target data set DS-S and the actual data set DS-I. The target data set DS-S is obtained based on a measurement of tooth **205** by sensor **203**. The digitally generated tooth model **221** comprises data on the spatial geometry of the dental restoration **205** and the assigned materials from which the dental restoration **207** is to be fabricated. The optical and physical properties required for rendering are known in the rendering software. These can be taken from a parameter table which is constantly being updated with new materials.

[0056] The actual DS-I data set is obtained from the tooth model **221** by subjecting the tooth model **221** to a rendering process that takes into account the spatial geometry of the dental restoration **205** and the optical and physical properties of the various materials that occur, including adhesive and die, if applicable.

[0057] The propagation of light in the tooth model **221** can be described by the Maxwell equations. For example, the rendering uses the Radiative Transport Equation (RTE), where a propagation medium is described by the absorption coefficient, scattering coefficient, refractive index, and scattering phase function. For example, the digital tooth model **221** includes data on the spatial geometry of the dental restoration **205** and the internal architecture as well as the absorption coefficient, scatter coefficient, refractive index, and scattered phase function for the respective materials of the architecture.

[0058] During rendering based on the tooth model **205**, the scattering phase function can be solved numerically with the above-mentioned parameters in a Monte Carlo simulation (ray tracing) with any desired accuracy, in which a large number of photons propagate on random paths through the tooth model. From this, an actual data set DS-I for the appearance of the dental restoration **205** can be calculated by rendering, which considers the materials used, the external shape and the internal architecture of the tooth model **221**. This calculated actual data set DS-I can then be compared with the target data set DS-S, which was obtained based on a neighboring tooth. To simplify the comparison, it can be performed in a two-dimensional derivative (two-dimensional image). A numerical value is calculated as a measure for a deviation $\Delta E_{S,I}$ between the actual data set and the target data set. The digital tooth model is then altered until the deviation $\Delta E_{S,I}$ is minimal or below a specified threshold value.

[0059] FIG. **3** shows a schematic representation for the calculation of a deviation $\Delta E_{S,I}$ between the target data set DS-S and an actual data set DS-I. For example, the DS-S data set includes a representation of tooth **205** in a given perspective. In contrast, the DS-I data set, which was rendered from the tooth model, comprises a representation of the tooth model in the same perspective. The two illustrations from the target data set DS-S and the actual data set DS-I are scaled to the same size and placed next to each other. The Euclidean deviation $\Delta E_{S,I}$ between the target data set DS-S and the actual data set DS-I can be calculated by summing up the differences in the color values of the pixels along the comparison lines **223**, for example in the L*a*b* color space. These comparison lines **223** can be shifted as desired, for example by moving the tooth halves together. In general, however, the comparison line **223** can also have a different course. The comparison can be performed at pixel level as the lowest resolution.

$$\Delta E_{S,I}=\sqrt{(L_S^*-L_I^*)^2+(a_S^*-a_I^*)^2+(b_S^*-b_I^*)^2}$$

[0060] The greater the difference in gradient along the comparison line **223**, the greater the numerical deviation $\Delta E_{S,I}$. If there is a perfect color match between the target data set DS-S and the actual data set DS-I, the deviation $\Delta E_{S,I}$ is zero. In general, however, other methods can be used to calculate the deviation $\Delta E_{S,I}$, such as those based on spectral information.

[0061] FIG. **4** shows a block diagram of a method for designing a dental restoration **207**. In the first step S**101**, a target data set DS-S is determined based on a natural tooth **205**, which reflects the optical properties, such as shade, shade scheme and translucency, and/or the geometry of the natural tooth **205**. Ideally, the target data set DS-S can be determined on a neighboring tooth **205** of the tooth to be replaced as a template. This has the advantage that the actual data set DS-I of the dental restoration **207** can be adapted as accurately as possible and in the same shade to the oral situation. In step S**102** the digital tooth model **221** with the internal architecture is generated, for example derived from an idealized tooth model from a tooth library, which serves as the basis for the further method. In step S**103**, the materials to be used and thus their optical and physical parameters of the internal architecture are assigned to the digital tooth model **221**. These are required to render the digital tooth model **221** and to generate the actual data set DS-I from it in the next step, which is to be used for the target/actual comparison.

[0062] Then, in step S**104** the deviation $\Delta E_{S,I}$ between the target data set DS-S and the actual data set DS-I is calculated. In step S**105**, the digital tooth model **221** is altered by assigning other materials and/or altering the internal architecture in such a way that a smaller deviation $\Delta E_{S,I}$ between the determined target data set DS-S and the newly generated actual data set DS-I is generated. Steps S**103** to S**105** are repeated iteratively until the deviation $\Delta E_{S,I}$ between the actual data set DS-I and the target data set DS-S has reached a minimum value or a specified convergence interval is reached (in the case of trade-offs, e.g. compliance with minimum wall thicknesses, limited availability of dental materials due to a tendency to reduce). The technical advantage of the method is that the dental restoration **207** can be fabricated with a biomimetic appearance that corresponds to that of the recorded natural tooth **205**. There is also the advantage that in the future, more appearances can be covered with a smaller range of materials.

[0063] The iterative method for the generation of biomimetic dental restorations **207** realizes a closed loop, which is run until the deviation $\Delta E_{S,I}$ between the actual data set DS-I and the target data set DS-S is at its lowest (closed loop). This applies, for example, to the patient-specific color measurement, preparation, modeling, simulation, and fabrication of the highly esthetic dental restoration **207**. This is an iterative, closed digital process in which the modeling and simulation of the dental restoration **207** approximates the natural appearance in the patient's mouth as closely as possible. The use of shade guides of any kind or a subjective comparison of images is not necessary since one is guided by the natural appearance and an automated comparison is performed.

[0064] The method for designing the dental restoration **207** is an iterative, closed digital process that brings the modeling and simulation of the dental restoration **207** as close as possible to the natural appearance in the patient's mouth. Because the optical parameters of the materials used are known and taken into account during rendering, the optical influencing factors of the different three-dimensional layers, such as preparation, cement layer, dentine and incisal layer, can be simulated for the first time in an optically realistic manner, resulting in a more realistic appearance for the inserted dental restoration **207**. By using materials with known optical and physical properties (optically calibrated materials) the user recognizes the biomimetic dental restoration **207** as realistic.

[0065] The technique enables a biomimetic, i.e., a tooth-like, layered structure of the dental restoration **207** that is remarkably close to nature to be realized in digital manufacturing processes such as milling and 3D printing with multiple materials. The color information from the target/actual comparison can also be used for the individual, selective coloring of a zirconium oxide whitener by infiltration. The process affects the entire digital workflow for indirect dental restorations and forms the basis for the implementation of dental esthetics including multi-material 3D printing.

[0066] All features explained and shown in connection with individual embodiments of the invention may be provided in different combinations in the subject-matter of the invention to simultaneously realize their beneficial effects.

[0067] All process steps can be implemented by devices that are suitable for carrying out the respective process step. All functions, which are executed by objective characteristics, can be a process step of a method.

[0068] In some embodiments, the innovations may be implemented in diverse general-purpose or special-purpose computing systems. For example, the computing environment can be any of a variety of computing devices (e.g., desktop computer, laptop computer, server computer, tablet computer, gaming system, mobile device, programmable automation controller, etc.) that can be incorporated into a computing system comprising one or more computing devices.

[0069] In some embodiments, the computing environment includes one or more processing units and memory. The processing unit(s) execute computer-executable instructions. A processing unit can be a central processing unit (CPU), a processor in an application-specific integrated circuit (ASIC), or any other type of processor. In a multi-processing system, multiple processing units execute computer-executable instructions to increase processing power. A tangible memory may be volatile memory (e.g., registers, cache, RAM), non-volatile memory (e.g., ROM, EEPROM, flash memory, etc.), or some combination of the two, accessible by the processing unit(s). The memory stores software implementing one or more innovations described herein, in the form of computer-executable instructions suitable for execution by the processing unit(s).

[0070] A computing system may have additional features. For example, in some embodiments, the computing environment includes storage, one or more input devices, one or more output devices, and one or more communication connections. An interconnection mechanism such as a bus, controller, or network, interconnects the components of the computing environment. Typically, operating system software provides an operating environment for other software executing in the computing environment, and coordinates activities of the components of the computing environment.

[0071] The tangible storage may be removable or non-removable, and includes magnetic or optical media such as magnetic disks, magnetic tapes or cassettes, CD-ROMs, DVDs, or any other medium that can be used to store information in a non-transitory way and can be accessed within the computing environment. The storage stores instructions for the software implementing one or more innovations described herein.

[0072] Where used herein, the term "non-transitory" is a limitation on the computer-readable storage medium itself—that is, it is tangible and not a signal—as opposed to a limitation on the persistence of data storage. A non-transitory computer-readable storage medium does not necessarily store information permanently. Random access memory (which may be volatile, non-volatile, dynamic, static, etc.), read-only memory, flash memory, memory caches, or any other tangible, computer-readable storage medium, whether synchronous or asynchronous, embodies it.

[0073] The input device(s) may be, for example: a touch input device, such as a keyboard, mouse, pen, or trackball; a voice input device; a scanning device; any of various sensors; another device that provides input to the computing environment; or combinations thereof. The output device may be a display, printer, speaker, CD-writer, or another device that provides output from the computing environment.

[0074] The scope of protection of the present invention is given by the claims and is not limited by the features explained in the description or shown to the figures.

1. A method for designing a dental restoration (**207**), comprising the steps:

determining (S**101**) a target data set (DS-S) based on a natural tooth (**205**), which reflects the optical properties and/or the geometry of the natural tooth (**205**);

generating (S**102**) a digital tooth model (**221**) with an internal architecture;

rendering (S**103**) the digital tooth model (**221**) based on the internal architecture to generate an actual data set that reflects the optical properties and/or the geometry of the digital tooth model (**221**);

calculating (S**104**) a deviation ($\Delta E_{S,I}$) between the target data set (DS-S) and the actual data set (DS-I); and

iterative altering (S**105**) the digital tooth model (**221**) to obtain a smaller deviation ($\Delta E_{S,I}$) between the determined target data set (DS-S) and the actual data set (DS-I) of the re-rendered digital tooth model (**221**).

2. The method according to claim **1**, wherein the deviation ($\Delta E_{S,I}$) is calculated on the basis of a Euclidean distance between the target data set (DS-S) and the actual data set (DS-I).

3. The method according to claim **1**, wherein the deviation ($\Delta E_{S,I}$) is calculated on the basis of a spectral distance between the target data set (DS-S) and the actual data set (DS-I).

4. The method according to claim **1**, wherein the target data set (DS-I) comprises data about a two-dimensional or three-dimensional image of the natural tooth (**205**), data about an exposure angle to the tooth (**205**), data about color information of the tooth (**205**), data about a color spectrum of the tooth (**205**) and/or data about geometry information of the tooth (**205**).

5. The method according to claim **1**, wherein the target data set (DS-S) is captured by a digital camera, a 3D scanner, a 3D camera system, a spectrometer, or a digitized color key.

6. The method according to claim **1**, wherein the target data set (DS-S) comprises optical properties of a residual tooth (**209**).

7. The method according to claim **6**, wherein the digital tooth model (**221**) is rendered on the basis of the optical properties of the residual tooth (**209**), the geometry of the residual tooth, the surrounding neighboring teeth, the oral situation, the consideration of the gingiva or gum color and/or the adhesive material used for fixing the dental restoration (**207**) on the residual tooth (**209**).

8. The method according to claim **1**, wherein the step of generating the digital tooth model (**221**) comprises the step of importing, calculating and/or specifying a tooth model (**221**) having a predetermined internal architecture.

9. The method according to claim **1**, wherein the digital tooth model (**221**) is rendered at an angle that corresponds to the shooting angle when capturing the tooth (**205**) and/or a predetermined light situation.

10. The method according to claim **1**, wherein the digital tooth model (**221**) is altered by changing a material assignment to a sub-volume.

11. The method according to claim **1**, wherein the digital tooth model (**221**) is altered by changing the sub-volume while retaining the outer geometry.

12. The method according to claim **1**, wherein the dental restoration (**207**) is fabricated based on the actual data set (DS-I).

13. The method according to claim **12**, wherein the dental restoration (**207**) is produced by means of a multi-material 3D printing device or a milling device.

14. A computer apparatus (**200**) for designing a dental restoration (**207**), comprising a sensor (**203**) for detecting a target data set based on a natural tooth, configured to perform the method according to claim **1**.

15. A computer apparatus (**200**) for designing a dental restoration (**207**) comprising a sensor (**203**) for detecting a target data set based on a natural tooth and a computing unit with at least one algorithm that is configured to perform the method of claim **1**.

16. A computer program comprising instructions that cause a computer device comprising a sensor (**203**) for detecting a target data set based on a natural tooth, to perform the process steps according to claim **1**.

17. A computer program product comprising program code which is stored on a non-transitory machine-readable medium, the machine-readable medium comprising computer instructions executable by a processor, which computer instructions cause the processor to perform the method according to claim **1**.

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