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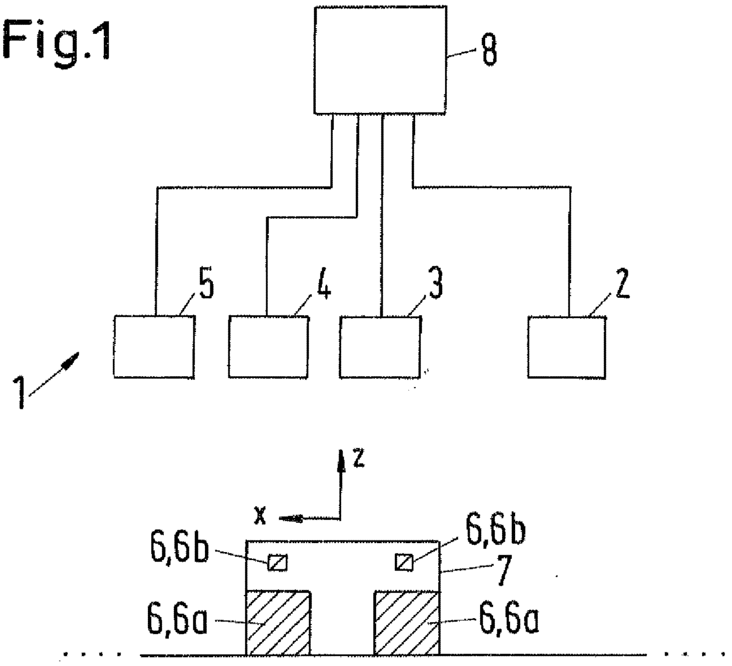
(54) Title of the Invention: **A method for three-dimensional color printing and a three-dimensional color printing device**
Abstract Title: **Three-dimensional colour printing**

(57) A method and device for three-dimensional colour printing is disclosed in which at least a first printing material with a first printing material colour and at least another printing material with another printing material colour are used to construct a printing object 7. An arrangement of the printing materials in a surface region and a near surface interior region of the printing object 7 is determined based on a desired colour reproduction of the printing object 7 and for each voxel of the surface region and the near surface interior region: a printing material colour vector is assigned to the voxel, a printing material sequence vector is determined depending on the printing material colour vector, one printing material of the printing material sequence vector is selected depending on a distance of the voxel to its respective closest surface voxel and the selected printing material is assigned to the voxel.

Fig.1



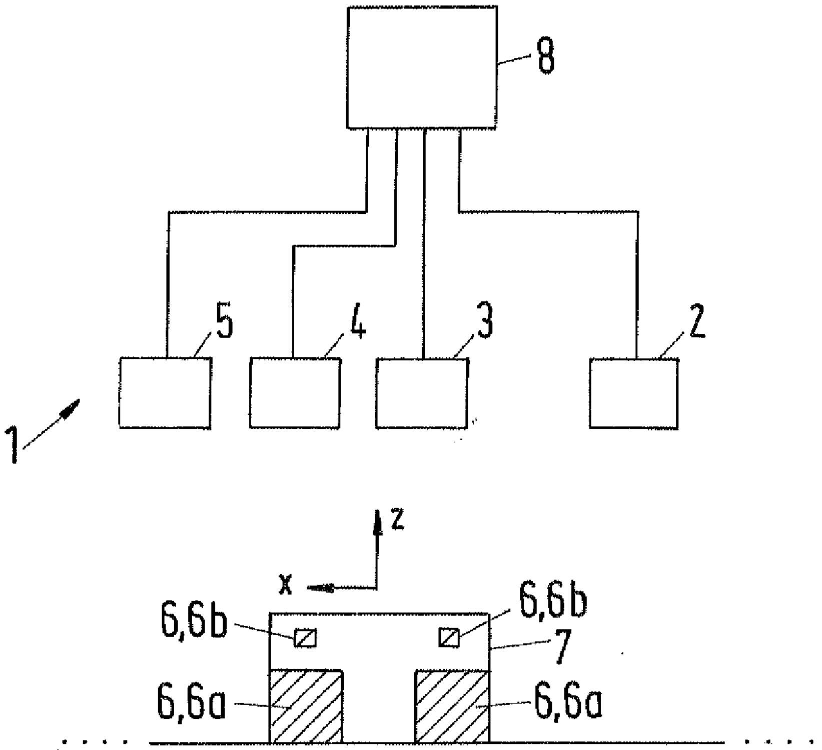


Fig.1

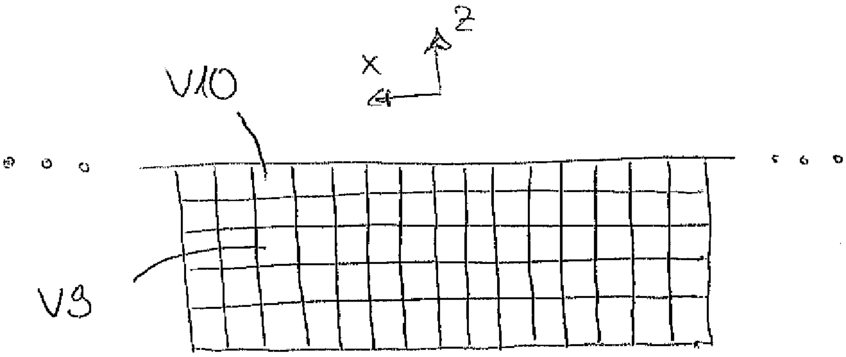


FIG.2

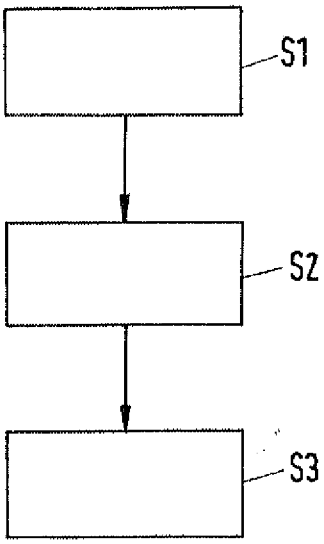


Fig.3

A method for three-dimensional color printing and a three-dimensional color printing device

The invention relates to a method for three-dimensional color printing and a three-dimensional color printing device.

Three-dimensional printing or 3D printing refers to processes for printing a 3D object which can be also refer to as printing object. Existing 3D printers can use a variety of printing materials, wherein only few materials can be combined simultaneously for printing a printing object. As a result, the color gamut of the said 3D printing device is restricted and corresponds to only a fraction of the color space as only a limited number of colors can be generated, in particular via subtractive or autotypical mixture.

Therefore, printing objects or parts thereof which have a color outside the color gamut of the 3D printing device result in a false color reproduction.

It is known to provide an arrangement of printing materials by using half-toning algorithms. The document “J. Morovic et al. “HANS A new color separation and half toning paradigm”, Color and Imaging conference, vol. 2010, no. 1, Society for Imaging Science and Technology, 2010 demonstrates that the color gamut volume depends on the half-toning algorithm.

Also known is to apply a chemical layer after printing is finished to enlarge a color gamut (see e.g. the document “S. Mourad et. al., “Doubling the color gamut volume of inkjet prints using simple-post processing” , Conference on Color and Graphics, Imaging, and Vision, vol. 2006, no. 1, Society for Imaging science and Technology, 2006”).

In so called powder- binder jetting systems, full-color objects can be printed. Corresponding 3D printers use an inkjet-based technology for coloring a base material (powder). Via a post-processing, e.g. an infiltration of epoxy or cyanoacrylate-based particles, the color gamut can be enlarged (see e.g. the document “M. Stanic et. al., “Color measurements of 3-dimensional ink-jet prints”, NIP and digital fabrication conference, vol. 2008, no. 2, Society for Imaging science and Technology, 2008”).

Further known is 3D printing by a method referred to as polyjetting or multi-jet modeling. Herein, multiple printing materials are combined. UV-hardening printing inks are deposited and hardened slice by slice. Actual 3D printers, however, can combine only a limited numbers of printing materials, e.g. only up to three printing materials.

It is further known to use support material within the 3D printing process. The support material is a material which is regularly used in the printing process temporarily, in particular to physically support overhanging parts or portions of the printing object. After the 3D printing process is finished, the support material is removed, e.g. in a removal step.

Accurate color reproduction is important in many applications of 3D printing, especially for design-prototypes or 3D copies, where a texture-mapped 3D scan of an object is to be reproduced in a color-consistent way. However, existing 3D printers, in particular the aforementioned polyjet printers, use colored printing materials which are highly translucent. Such materials have high transmission and scattering properties, which effectively result either in blurring of color edges, or severe dot-gain if care is not taken to account for these properties. Thus, the organization of the printing materials within significant distance to the surface of the printing object, e.g. as much as a half a centimeter, can greatly affect the perceived color. It is therefore highly important to control material placement several layers of voxels beneath the surface, taking into account the transmission and scattering properties of the materials, greatly complicating the computational aspects of half-toning algorithms.

EP 14 194 608.7 (application number, not yet disclosed) discloses a method for three-dimensional color printing, wherein at least first printing material with a first printing material color and at least another printing material with another printing material is used to construct a printing object, wherein an arrangement of the printing materials in a surface region and a near surface interior region of the printing object is determined based on a desired color reproduction of the printing object.

There is the technical problem of providing a method for 3D color printing and a 3D color printing device which allow a fast computational and efficient processing of desired printing data, in particular a generation of control data for printing.

The solution to said technical problem is provided by the subject-matter with the features of the independent claims 1 and 14. Further advantageous embodiments are provided by the subject-matter with the features of the remaining sub claims.

A method for three-dimensional color printing (3D printing) is proposed. At least a first printing material with a first printing material color is used to construct a printing object. In other words, the at least first printing material is used to generate or build the printing object or a part thereof. The printing object can denote the object which is to be printed, i.e. constructed by the proposed method. The 3D printing process used to construct the printing object is known to the skilled person.

In particular, the printing process can comprise the generation of successive slices in a vertical direction (Z-direction), wherein the slices can be oriented parallel to a plane spanned by a longitudinal direction (X-direction) and a lateral direction (Y-direction). The mentioned directions can provide directions of a reference coordinate system. A slice denotes a two-dimensional cross section through the printing object, e.g. with a predetermined thickness, wherein the section plane is perpendicular to the aforementioned vertical direction.

Before printing, e.g. in a modelling step, a model of the 3D printing object can be created, e.g. by computer aided design (CAD). A model can also be generated by 3D-scanning with captured color texture data.

Based on the model of the 3D printing object, control data for a 3D printing device can be generated wherein the control data is used to control the printing process. Within the modelling step, a desired color can be assigned to the printing object or parts thereof. As a result, the control data can encode color information of the printing object, e.g. in form of a color vector, wherein entries of said color vector correspond to intensities of a desired color. The desired color does not necessarily need to correspond to a printing material color.

The 3D color printing process can e.g. be an extrusion-based process, a wire-based process, a granular- based process, a powder-bed process or a lamination-based process.

Preferably, the 3D color printing process is a polymerization-based process. In polymerization-based printing processes, liquid printing materials with predetermined printing material colors, e.g. liquid photopolymers, are applied into or onto a layer and exposed to radiation, e.g. to a laser beam, in order to harden the exposed printing material. Printing materials can e.g. be translucent printing materials. For example, printing materials can be provided by printing inks wherein the printing inks can be hardened after their application onto or into a layer, e.g. by exposure to light, in particular to UV radiation.

The printing inks can have different colors. This process can also be referred to as polyjetting which is also known as multi-jet processing.

It is further possible to use least one support material with a first support material color to support the construction of the printing object. The support material can e.g. be used to physically support overhanging parts or portions of the printing object. The support material is defined as described previously. The support material can also be a translucent material. In particular, the support material denotes a material which can be removed from the printing object in a non-destructive way, e.g. in a removal step subsequent to the printing process. In particular, the support material can denote a material which can be removed mechanically, e.g. by a water jet, or chemically, e.g. by resolving the support material in a chemical bath. The support material can e.g. be solvable by a solvent, wherein the printing material is not solvable by said solvent. The solvent can e.g. be water. Alternatively or in addition, a robustness or strength, in particular a compressive strength and/or an ultimate tensile strength and/or a bending strength and/or a torsional strength and/or a shear strength, of the support material can be smaller than the strength of the printing material(s). In particular, the maximal strength of the support material can be smaller than a predetermined percentage of the minimal strength of the printing material with the minimum strength, e.g. smaller than 0.9, smaller than 0.75, smaller than 0.5 or smaller than 0.3 of the minimal strength.

Further, at least another printing material with another printing material color is used to construct a printing object. Preferably more than two, e.g. three, printing materials are used to construct the printing object, wherein all printing materials have different printing material colors. The colors of the printing materials can define corners of the color gamut. The color gamut is defined by mixing the printing materials.

Further, an arrangement of the printing materials in a surface region and a near-surface interior region of the printing object is determined based on a desired color reproduction of the printing object. In other words, the arrangement of printing materials during printing of the printing object is chosen such that the printing object or volume fractions thereof reproduce the desired color or such that a coloring defect which denotes a deviation between a desired color reproduction and the provided color reproduction, is reduced or minimized. The arrangement of printing materials can be determined based on optical characteristics of the printing materials, e.g. based on scattering and/or translucence characteristics, in particular such that the printing object or volume fractions thereof reproduce the desired color or such that a coloring defect which denotes a deviation between a desired color reproduction and the provided color reproduction, is reduced or minimized.

Further, the printing materials can be arranged within the surface region and within the near-surface region according to the determined arrangement in a printing step. Within the printing step, a printing device can be controlled such that the printing materials are arranged accordingly. A reproduction of colors or color tones can be generated by an adequate spatial arrangement of unit volumes (defined by the printer resolution), referred to as voxels, filled by printing materials with different printing material colors. A remaining region of the printing object can be provided by a reference printing material which will be explained later.

This means that not only the arrangement of materials in the surface region but also in interior regions is taken into account for providing a desired colorization of the printing object.

This advantageously improves the color reproduction of the resulting printing object, e.g. as it increases the color gamut if translucent printing materials are used.

A voxel-based representation of the printing object can be determined, wherein a surface layer voxel set and a near-surface interior voxel set are determined. The surface layer voxel set can comprise all voxel intersected by the surface of the printing object. The set of near-surface interior voxels preferably comprises only a subset of all interior voxels. In the context of this invention, the surface layer voxel set can also be referred to as surface voxel shell and the near-surface interior voxel set can also be referred to as the interior voxel shell. A voxel layer or shell does not necessarily correspond to a slice which is printed during the printing process. The process of decomposing the printing object into voxel can also be referred to as voxelization. Such a process is known to the skilled person.

According to the invention, the following steps are processed for each voxel of the surface region and the near-surface interior region.

In a first step, a printing material color vector is assigned to the voxel.

It is, for instance, possible to assign desired color values, e.g. a sRGB color value, to a surface of the printing object, e.g. in the modelling step. As such a desired color value is not necessarily equal to a printing material color, the desired color value can be converted into a printing material color vector, wherein the printing material color vector comprises one entry per printing material and the value of an entry corresponds to a portion of the respective printing material color to reproduce the desired color. For example, a sRGB color can be mapped to a printing material color vector of (c, m, y) where c is the tonal value for cyan, m is the tonal value for magenta and y is the tonal value for yellow. Entries of the printing material color vector can also be referred to as tonal value, wherein a tonal value defines the local percentage of the printing material. Thus, the printing material color vector can also be referred to as tonal value vector. The printing material color vector represents the amount or intensity of each printing material required to reproduce the desired color.

It is possible that a reference printing material color exists, wherein the printing material color vector does not comprise an entry (tonal value) related to the reference printing material color. The reference printing material color can be the color of one of the used printing materials. The reference printing material color can e.g. be a white color. A printing material color vector which does not comprise an entry (tonal value) related to the reference printing material color can e.g. be referred to as reduced printing material color vector.

The color-related entry can be a numerical value encoding a desired intensity of said printing material color, in particular in a volume fraction of the printing object. The numerical values can e.g. be chosen from a printing material color value interval, e.g. an interval from 0 (inclusive) to 1 (inclusive) or an interval from 0 (inclusive) to 255 (inclusive).

In other words, the printing material color vector can comprise one entry per printing material of a 3D printing device. As mentioned before, such a vector can comprise an entry for a reference printing material color. Preferably, the printing material color vector is a reduced printing material color vector which comprises one entry per available printing material except for the printing material color of the reference printing material.

Moreover, it is possible to discretize the printing object into a set of object voxels. Surface voxels can be voxels of a boundary layer of the printing object, wherein the boundary layer is the barrier layer or the transition layer between the printing object and the exterior. Thus, surface voxels can comprise the voxels of the printing object that separate interior from external voxels or voxels which are intersected by a printing object surface. Interior voxels can denote the remaining voxels of the printing object. In particular, an interior voxel can denote an object voxel which is fully enclosed by surface voxels.

It is further possible that a desired color value is assigned to each voxel, in particular to each surface voxel, wherein this desired color value is subsequently converted into the printing material color vector. Then, the printing material color vector is assigned to the voxel. Alternatively, the desired color value can be first converted and subsequently assigned to a voxel, in particular a surface voxel.

Further, one of the printing materials can be assigned to each surface voxel. Moreover, one of the printing materials can be assigned to each near-surface interior voxel.The assignment of a printing material to a voxel is based on the desired color reproduction of the printing object. A reference printing material which will be explained later can be assigned to the remaining interior voxels. It is, for instance, possible to assign one of the printing material colors to a voxel. Then, the corresponding printing material is assigned to said voxel.

The assignment of one of the printing materials or one of the printing materials colors to a voxel can e.g. be provided by a half-toning algorithm. Half-toning algorithms are known to the skilled person. Advantageous half-toning processing methods will be described in the following.

It is possible to perform a half-toning algorithm to assign a printing material only to voxels of the surface layer voxel set. An assignment of a printing material to voxels of the near-surface interior voxel set can subsequently by determined based on the printing material assignment to the voxels of the surface layer voxel set. Thus, the assignment of a printing material to a voxel of the near-surface interior voxel set is performed independent of a half-toning algorithm, in particular not using a half-toning algorithm. Alternatively, it is possible to perform a half-toning algorithm to assign a printing material to voxels of the surface layer voxel set and a half-toning algorithm to assign a printing material to voxels of the near-surface interior voxel set.

It is, for instance, possible that a printing device is controlled such that the volume fraction of the printing object which corresponds to a voxel is provided or constructed by the printing material assigned to the voxel. That a printing material is used to construct the printing object means that at least one object voxel is filled by the printing material or that an object voxel is provided by the printing material. A size of the voxel can depend on a resolution of the printing process. The resolution of the printing process can e.g. be 300 dpi in a plane spanned by the X-direction and the Y-direction and 600 dpi in the Z-direction, wherein the directions X, Y, Z, provide a Cartesian coordinate system. In the printing step, the voxels can thus be provided by the material assigned to the respective voxel, e.g. by a printing device.

In a further step, a printing material sequence vector is determined depending on the printing material color vector. The printing material sequence vector can have a predetermined dimension. An entry of the printing material sequence vector encodes or corresponds to a printing material.

An entry of the printing material sequence vector can be assigned to a voxel depending on a distance of that voxel to its closest surface voxel. The distance to the closest surface voxel can be provided by a value of a distance-to-surface function which provides the minimum distance of a voxel to the surface according to a given metric. For a surface voxel, the distance-to-surface function can have a value of zero.

Alternatively, an entry of the printing material sequence vector can be assigned to a voxel depending on a distance of that voxel to empty. The distance to empty can be provided by a value of a distance-to-empty function which provides the minimum distance of a voxel to the volume outside the printing object according to a given metric. For a surface voxel, the distance-to-surface function can have a value which corresponds to the minimal voxel step size. In general, the distance of the voxel to its closest surface voxel can be replaced by the distance of the voxel to empty.

A set of distance intervals can be defined so that each distance falls into one of these intervals. Further, the distance intervals can be sorted, e.g. according to the increase of distance values within these intervals. Further, a number or index can be assigned to each distance interval in an ascending order. Further, an entry of the printing material sequence vector can be assigned to a voxel according to its index in the printing material sequence vector, wherein the index corresponds to the number or index of the interval which comprises the distance of said voxel to its closest surface voxel.

It is possible that the near surface region is divided into one or multiple interior layer voxel sets. This will be explained later in more detail. In this case, the dimension of the printing material sequence vector can correspond to the number of the interior layer voxel sets increased by one. In other words, the printing material sequence vector can comprise one entry per layer voxel set. The number of interior layer voxel sets can be predetermined. In particular, the number can be chosen from an interval ranging from 1 (inclusive) to any integer value. The entries of the printing material sequence vector can be assigned to each layer voxel set according to their index in the printing material sequence vector. For instance, a first entry of the printing material sequence vector can be assigned to the surface layer voxel set, wherein a second entry can be assigned to the first interior layer voxel set, and so on.

In a further step, one printing material of the printing material sequence vector is selected depending on a distance of the voxel to its respective closest surface voxel. The distance can be determined by using the aforementioned distance-to-surface function. As aforementioned, the distance can be assigned to a distance interval, wherein one entry of the printing material sequence vector is assigned to the distance interval.

In a further step, the selected printing material is assigned to the voxel.

This advantageously allows a fast computational assignment of the one printing material to a voxel which provide a desired quality of a color reproduction, in particular if translucent printing materials are used.

In another embodiment, a surface layer voxel set and a near-surface interior voxel set are determined, wherein the surface layer set comprises all surface voxels. This has been explained before and allows an effective handling of the printing process in terms of speed and required computing capacity.

In another embodiment, at least one, preferably more than one, interior layer voxels set/s of the printing object is/are determined, wherein the distance of all voxels of the interior layer voxel set to a respective closest surface voxel are within a predetermined distance interval of non-zero distances.

The distance can denote a minimal distance from the respective voxel of the interior layer voxel set to a surface voxel, i.e. the distance to the nearest surface voxel. The distance can be measured within the aforementioned three-dimensional reference coordinate system.

Further, a printing material color vector of the closest surface voxel is assigned to each voxel of the interior layer voxel set. This means that the printing material color vector of the surface voxel which is the closest surface voxel of the respective voxel is assigned to said voxel. A size of the distance interval can be chosen depending on the printing object. Also, the size of the distance interval can correspond to the voxel size along the dimension with the minimal resolution. In other words, each voxel of the interior layer voxel set is initialized with the printing material color vector of the closest surface voxel.

It is possible that the closest distance of an interior voxel is provided between said interior voxel and multiple surface voxels. In this case, any algorithm can be used to select a surface voxel from the set of surface voxels which each have the closest distance to the interior voxel. For example, the surface voxel can be selected randomly from said set of surface voxels. Alternatively, the first surface voxel of said set of surface voxels according to some arbitrary order can be selected. Further, the printing material color vector of the randomly selected surface voxel can be assigned to the interior voxel.

It is also possible to determine a fused printing material color vector from the printing material color vectors of all surface voxels from the set of surface voxels which each have the closest distance to the interior voxels and to assign this fused printing material color vector to the interior voxel. To determine the fused printing material color vector, any function can be used, e.g. an average function or a median function. The function can also be a channel-specific function, e.g. a channel-specific average or channel-specific median function.

This advantageously allows a performance-effective processing of interior voxels, i.e. a subsequent effective assignment of a printing material to an interior voxel.

Also, multiple interior layer voxel sets of the printing object can be determined. The distances of all voxels of one interior layer voxel set to a respective closest surface voxel are within a layer-dependent predetermined distance interval, wherein a printing material color vector of the closest surface voxel is assigned to each voxel of the interior layer voxel set. Of course, the layer-dependent distance intervals are different from one another. Distance intervals, however, can be chosen adjacent to one another. As an example, one, two, three, four or five interior layer voxel sets can be determined.

The distance interval can comprise values between (k-1) x ls (inclusive) and k x ls, wherein k=2…kmax. In this formulation, kmax denotes the number of interior layer voxel sets and ls denotes the size of the respective distance intervals. In this case, the distance interval for k=1 represents the surface layer voxel set. By increasing kmax, the color gamut can be increased.

The distance interval(s) of the at least one interior layer voxel set can be chosen such that all voxels of the near-surface interior voxel set are assigned to one of the interior layer voxel sets.

To improve computational efficiency, an interior layer voxel set can be provided by a minimally thick subset of the set of interior voxels which have distances to the nearest surface voxel within the predetermined distance interval for said layer. The thickness of said layer which can correspond to the range of the distance interval can e.g. correspond to the minimal resolution or the resolution in at least one axis.

In another embodiment, at least one, preferably more than one, interior layer voxel set/s of the printing object is/are determined, wherein the distances of all voxels of the interior layer voxel set to a respective closest surface voxel are within a predetermined distance interval of non-zero distances. This has been explained before.

Further, an assignment of one of the printing materials to each voxel of the surface layer voxel set is performed independently of an assignment of one of the printing materials to each voxel of the at least one interior layer voxel set. Alternatively or in addition, an assignment of one of the printing materials to each voxel of one interior layer voxel set is performed independently of an assignment of one of the printing materials to each voxel of at least one other interior layer voxel set. In particular, an assignment of one of the printing materials to each voxel of one interior layer voxel set is performed independently of an assignment of one of the printing materials to each voxel of each of all remaining interior layer voxel set/s.

In general, the assignment of one of the printing materials to each voxel of a layer voxel set can be performed independent from the assignment of one of the printing materials to each voxel of any one of the remaining layer voxel sets.

In particular, the assignment of one of the printing materials to each voxel of the surface layer voxel set can be provided by performing by a contoning algorithm, e.g. a sequence-based contoning or a probability contoning which will be explained later. Further, the assignment of one of the printing materials to each voxel of any one of the at least one interior layer voxel set can also be provided by performing a contoning algorithm. The contoning algorithms, however, are performed independently for each layer voxel set. This can be referred to as layered contoning.

That an assignment of one of the printing materials to each voxel of the surface layer voxel set is performed independently of an assignment of one of the printing materials to each voxel of the at least one interior layer voxel set can mean that distribution of printing materials in one layer voxel set is uncorrelated to the distribution of printing materials in one or each of the remaining layer voxel sets.

In another embodiment, at least one interior layer voxel set of the printing object is determined, wherein the distances of all voxels of the interior layer voxel set to a respective closest surface voxel are within a predetermined distance interval of non-zero distances. This has been explained before

Further an assignment of one of the printing materials to each voxel of one layer voxel set is performed such that the distribution or arrangement of printing materials in said layer voxel set is uncorrelated to the distribution or arrangement of printing materials in one or each of the remaining layer voxel sets.

In particular, an assignment of one of the printing materials to each voxel of the surface layer voxel set is performed such that the distribution of printing materials in said surface layer voxel set is uncorrelated to the distribution of printing materials in at least one or each of the interior layer voxel sets. Alternatively or in addition, an assignment of one of the printing materials to each voxel of one interior layer voxel set is performed such that the distribution of printing materials in said interior layer voxel set is uncorrelated to the distribution of printing materials in at least one or each of the remaining layer voxel sets, wherein the remaining layer voxel sets comprise the surface layer voxel set and, if applicable, one or more other interior layer voxel set/s.

In order to determine a correlation between the distributions of printing materials in two different layer voxel sets, the voxels of a layer voxel set, in particular of an interior layer voxel set, can be projected to the surface layer voxel set. By projecting a layer voxel set to the surface layer voxel set, a projection surface layer voxel set can be determined. The voxel arrangement of the projection surface layer voxel set is similar to the voxel arrangement of the surface layer voxel set. If the correlation between the distributions of the printing materials in the surface layer voxel set and an interior voxel layer set is to be determined, the projection surface layer voxel set of the surface layer voxel set equals the surface layer voxel set.

For a selected layer voxel set, said projection surface layer voxel set can e.g. be determined by traversing each voxel of the projection surface layer voxel set, wherein, for each voxel of the projection surface layer voxel set, the printing material of the closest voxel of the selected layer voxel set is assigned to said voxel of the projection surface layer voxel set. This means that the printing material of the voxel of the selected layer voxel set with the smallest distance to the voxel of the projection surface layer voxel set is assigned to said voxel of the projection surface layer voxel set.

It is possible that the closest distance is provided between said voxel of the projection surface layer voxel set and multiple voxels of the selected layer voxel set. In this case, any algorithm can be used to select a voxel from the subset of voxels of the selected layer voxel set which each have the closest distance to the voxel of the projection surface layer voxel set. For example, the voxel can be selected randomly from said subset of voxels. Alternatively, the first voxel of said subset voxels according to some arbitrary order can be selected. Further, the printing material of the selected voxel can be assigned to the voxel of the projection surface layer voxel set.

It is also possible to determine a fused printing material from the printing material of all voxels from the subset of voxels which each have the closest distance to the voxel of the projection surface layer voxel set and to assign this fused printing material to the voxel of the projection surface layer voxel set. To determine the fused printing material color vector, any function can be used, e.g. an average function or a median function. The function can also be a channel-specific function, e.g. a channel-specific average or channel-specific median function.

Then, the correlation, e.g. in terms of a correlation coefficient, can be determined between the distributions of printing materials in the two projection surface layer voxel sets. The distributions of printing materials in two layer voxel sets can e.g. be uncorrelated if the correlation or absolute value of the correlation is smaller than a predetermined threshold value.

The correlation can e.g. also be determined for each of the printing materials, i.e. as a material-specific correlation. It is, for instance, possible, to determine a material-specific binary projection surface layer voxel set. Such a material-specific binary projection surface layer voxel set can comprise voxels with a first value, e.g. one, if the corresponding printing material is assigned to said voxels. Further, the material-specific binary projection surface layer voxel set comprises voxels with a second value, e.g. zero, if the corresponding printing material is not assigned to said voxels. Then, a Pearson correlation can be used to determine the correlation between two material-specific binary projection surface layer voxel set.

The distributions of printing materials in two layer voxel sets can also be uncorrelated if the absolute value of the difference between the correlation of the distributions of printing materials in the corresponding projection surface layer voxel sets and the autocorrelation of the distribution of the printing materials in one of the corresponding projection surface layer voxel sets is smaller than a predetermined threshold value and if the absolute value of the difference between the correlation of the distributions of printing materials in the corresponding projection surface layer voxel sets and the autocorrelation of the distribution of the printing materials in the remaining projection surface layer voxel set is smaller than the predetermined threshold value.

The autocorrelation can denote a correlation of a projection surface layer voxel set with a shifted projection surface layer voxel set. The shifted projection surface layer voxel set can be shifted by a predetermined amount of voxels, e.g. one, two or more voxel/s.

The predetermined threshold value can be a small value, e.g. equal to 0.1.

If the correlation is determined material-specific, the correlation and auto-correlation is determined for the corresponding material-specific binary projection surface layer voxel set. The distributions of printing materials in two layer voxel sets can e.g. be uncorrelated if the aforementioned criteria are fulfilled for each printing material.

Providing the uncorrelated distribution advantageously ensures a good printing quality.

In another embodiment, the printing material sequence vector is determined on a printing material portion vector, wherein the printing material portion vector is determined depending on the printing material color vector or reduced printing material color vector. The entries of the printing material portion vector define the amount of each material per unit volume. A unit volume can comprise one or more voxel(s), in particular one or more surface voxel(s). In particular, a mixture of printing materials according to the printing material portion vector allows the color reproduction within an acceptable color error tolerance.

Entries of the printing material portion vector can correspond to portions of one of the printing materials with respect to unity. The printing material portion vector can be a standardized vector and can have a norm, e.g. a L1 norm, of 1. It is possible that the printing material color vector can be un-standardized, wherein a norm of the printing material color vector is unequal to 1.

A maximum dimension of the printing material portion vector can be equal to the number of available printing materials, e.g. of a 3D printing device.

It is, however, possible that the dimension of the printing material portion vector can be lower than, equal to or higher than the dimension of the printing material color vector. It is, for instance, possible, to select only some but not all of the available printing materials of a 3D printing device. In this case, the dimension of the printing material portion vector can be equal to the number of selected printing materials.

In other word, the printing material portion vector can be determined based on a transformation which transforms the printing material color vector into the printing material portion vector.

The printing material sequence vector can then be determined such that the ratio of the entries of the printing material portion vector which are assigned to two different printing materials, i.e. the printing material portions, corresponds to the ratio of the number of the entries within the printing material sequence vector which are assigned to the said printing materials.

Alternatively, the printing material sequence vector can be determined such that a deviation or difference between the ratio of the entries of the printing material portion vector which are assigned to two different printing materials, i.e. the printing material portions, and the ratio of the number of the entries within the printing material sequence vector which are assigned to the said printing materials is minimal.

This advantageously allows to map (quantize) an e.g. 8 bit tonal value per channel to a controllable bit depth exploiting the translucency of the printing materials. This is in contrast to halftoning where each channel is quantized to a bit depth of 1.

In a preferred embodiment, the printing material portion vector is determined depending on the printing material color vector by an interpolation method. The interpolation method can e.g. be a multidimensional interpolation, e.g. a trilinear interpolation.

If m is the number of usable or available printing materials (including the reference printing materials) and o is the dimension of the printing material color vector (e.g. except the reference printing material), the transformation can be a transformation from o-dimensional vector to a m-dimensional vector. The transformation can e.g. be provided by assigning m-dimensional vectors of unit length to corners of an o-dimensional cube, wherein the cube can be referred to as color value cube or tonal value cube. The m-dimensional vectors assigned to the corners can be referred to as printing material portion vectors which are assigned to corresponding printing material color vectors located at the cube's corners. Then, a multidimensional interpolation can be used in order to determine the printing material portion vector. In other words, printing material portion vectors belonging to intermediate printing material color vectors are determined by interpolation.

It is possible that in this case, the material percentages or portions within the printing material portion vector are summed up to 1. This is, for instance, the case if the interpolation is a multilinear interpolation and the unit length of the material portion vectors is with respect to the 1-norm.

Using an interpolation approach, e.g. multidimensional interpolation, advantageously allows a fast and reliable determination of the printing material portion vector, wherein the desired color reproduction is ensured.

In another embodiment, the number of entries of the printing material sequence vector which are assigned to one of the printing materials are determined depending on the printing material portion vector and the predetermined dimension of the printing material sequence vector. This can be performed for each of the printing materials. In particular, the number of entries of the printing material sequence vector which are assigned to one of the printing materials are determined depending on or proportional to the magnitude of the entries of the printing material portion vector and the predetermined dimension of the printing material sequence vector.

In particular, the number of entries of the printing material sequence vector which are assigned to one of the printing materials are determined such that a deviation between the ratio of the magnitude of the entries of the printing material portion vector which are assigned to different printing materials and the ratio of the number of entries of the respective printing materials in the printing material sequence vector is minimal. This has been explained before.

Further, a material- ordered printing material sequence vector is determined, wherein the entries of the printing material sequence vector are determined such that the number of entries assigned to one printing material corresponds to the determined number.

The material-ordered printing material sequence vector can denote a vector, wherein the sequence of entries is provided by successive subsets of entries which comprise only one printing material. The sequence of successive subsets can be chosen randomly.

This means that if the dimension of the printing material sequence is 5 and the number of entries of said vector which is assigned to the printing material cyan is 2, the number of entries assigned to the printing material magenta is 2 and the number of entries assigned to the printing material yellow is 1 and the numbers of entries assigned to the printing material white is 0, a material-ordered printing material sequence vector can be provided by (CCMMY) or by (MMCCY) or (YCCMM) and so on. This advantageously allows a computationally fast and efficient determination of the printing material sequence vector for each voxel.

In another embodiment, a product of the magnitude of a material-specific entry in the printing material portion vector and the dimension of the printing material sequence vector is determined. The material-specific entry can denote the entry in the printing material portion vector which is assigned to one of the printing materials. Further, the number of entries of the printing material sequence vector is determined by rounding the product to the nearest integer value depending on a randomized rounding threshold. The randomized rounding threshold can be chosen from an interval ranging from 0 (exclusive) to 1 (exclusive). The randomized rounding threshold can be randomly determined according to a uniform distribution. It is possible that the randomized rounding threshold can be randomly determined for each material-specific entry or for each voxel.

Using the randomized rounding threshold advantageously allows to minimize the deviation between the ratio of the entries assigned to different printing materials of the printing material portion vector and the ratio of the number of entries for these different printing materials of the printing material sequence vector in a subset of the printing object which comprises multiple voxels. As a matter of fact, it might not always possible that said ratio of the entries of the printing material portion vector is equal to the ratio of the number of entries of the printing material sequence vector which are assigned to one of the printing materials. As a result, the color reproduction may be negatively affected. This, however, can be compensated by using different rounding thresholds for neighbouring voxels of a predetermined subset.

This advantageously allows the aforementioned computationally fast and efficient determination of the printing material sequence vector, wherein a color reproduction is only minimally effected.

In another embodiment, the printing material sequence vector is determined such that the probability for selecting one of the printing materials for an entry of the printing material sequence vector is similar to the ratio between the magnitude of the material-specific entry in the printing material portion vector and the sum of the magnitudes of all entries in the printing material portion vector. As will be explained later, determining the printing material sequence with said property can comprise an entry-per-entry determination, e.g. by a probability contoning, and an adequate ordering of predetermined entries, e.g. by a sequence-based contoning, in particular a Halton sequence-based contoning. The term “similar” also comprises the meanings of “almost” and “approximately equal”.

In another embodiment, a reordered printing material sequence vector is determined depending on the material-ordered printing material vector, wherein entries of the material-ordered printing material vector are reordered such that the sequence of reordered entries corresponds to a sequence in which the probability for selecting one of the printing materials for an entry of the printing material sequence vector is similar to the ratio between the magnitude of the material-specific entry in the printing material portion vector and the sum of the magnitudes of all entries in the printing material portion vector. In other words, the sequence of the entries in the reordered printing material sequence vector could be the result of determining the sequence entry-by-entry, wherein the probability for selecting one of the printing materials for the respective entry is similar to the ratio between the magnitude of the material-specific entry in the printing material portion vector and the sum of the magnitudes of all entries in the printing material portion vector.

This means that the entries of the material-ordered printing material vector a reordered such that the desired characteristic of the reordered printing material characteristic is achieved.

In particular, the reordered printing material sequence vector can be determined depending on the material-ordered printing material vector by a Halton sequence-based approach. It is for instance possible to generate a Halton sequence based on an arbitrary number, in particular a prime number. Then, an entry of the material-ordered printing material vector at a certain index can be assigned to the entry of the Halton sequence vector with the same index. This means that the first entry of the material-ordered printing material vector is assigned to the first entry of the Halton sequence vector and so on. If all entries of the material-ordered printing material vector are assigned to the respective entry of the Halton sequence vector, the entries of the material-ordered printing material vector can be reordered according to the magnitude of the corresponding entry of the Halton sequence vector. This advantageously ensures a high frequency arrangement of printing materials with a desired material percentage.

Of course, other approaches can be used to determine the reordered printing material sequence vector. For example, a Farthest-Point-Sampling approach can be used.

In an alternative embodiment, the printing material for one entry of the printing material sequence vector is determined probabilistically, wherein the probability for selecting one of the printing materials for the respective entry is similar to the ratio between the magnitude of the material-specific entry in the printing material portion vector and the sum of the magnitudes of all entries in the printing material portion vector. In this case, entries of the printing material sequence vector can be determined entry-by-entry.

In this embodiment, a material-ordered printing material sequence vector is not required in the implementation and only a probabilistic selection of the printing material according to the printing material portion vector can be performed.

It is, for instance possible, to determine a cumulative printing material portion vector, wherein an entry of the cumulative printing material portion vector corresponds to the sum of the corresponding entry in the printing material portion vector and the preceding entries of the printing material portion vector. The last entry of the cumulative printing material portion vector will be 1.

Further, an interval between 0 (exclusive) and the first entry of the cumulative printing portion vector will be assigned to a first printing material. Further, the intervals between the remaining entries of the cumulative printing material portion vector will be assigned to one of the remaining printing materials, respectively. Then, a vector of approximately or exactly uniformly distributed numbers between 0 and 1 can be determined, wherein a dimension of the vector of approximately or exactly uniformly distributed numbers equals to the dimension of the printing material sequence vector. The dimension defines the number of entries of the vector. One way to generate a set of approximately or exactly uniformly distributed numbers is to use a random number generator.

For each entry of the vector of approximately or exactly uniformly distributed numbers, the interval which comprises the respective value of the number and the printing material which is assigned to that interval is determined. Then, this printing material is assigned to the entry of the printing material sequence vector which has the same index as the entry of the uniformly distributed number within the vector of uniformly distributed numbers.

This advantageously ensures that a material percentage is well represented in average, but not necessarily in a single material sequence. A different random number generator can be taken and seeded with the slice number for implementation purposes.

It is possible that the voxels of a layer voxel set are traversed voxel-by-voxel. Further, all voxels of different layer voxel sets can be processed in parallel.

In another embodiment, at least one support material with the support material color is used as an additional printing material, wherein the at least one support material color is selected that the color gamut defined by the printing material color/s is extended.

This embodiment has been described within EP 14 194 608.7, wherein the disclosure of said document is fully incorporated by reference into this enclosure, in particular all embodiments described in the disclosure of EP 14 194 608.7.

In particular, a support material is only used to construct or provide an interior voxel. Further, an arrangement of printing material and support material can be provided such that a number of voxels of a set of connected support material voxels is smaller than a predetermined support material voxel number if at least one of this support material voxels is a surface layer voxel. Further, an arrangement of print material and support material is provided such that the spatial frequency spectrum of support material voxels has spectral components for non-zero frequencies whose absolute values are larger than 0. Further, an arrangement of printing material and support material can be provided such that a transmittance of the object voxels along an optical path between the support material voxel and a printing object environment is higher than a desired threshold value. Further, a percentage of support material used to construct the printing object and/or a predetermined volume fraction of the printing object is smaller than a predetermined threshold value. Further, the printing process can be at least partially controlled by a printing material color vector, wherein the maximum admissible support material color vector of the support material color-related entry is smaller than the admissible printing material color value of the printing material color-related entries.

Further proposed is a three-dimensional color printing device (3D printer), wherein the printing device comprises a means for printing a first printing material with a first printing material color, e.g. a first print head. Further, the printing device comprises a means for printing at least another printing material with another printing material color and at least one control unit. The means for printing a first printing material is controlled such that the first printing material is used to construct a printing object, wherein the means for printing the at least one other printing material is controlled such that the at least one other printing material is used to construct the printing object. The means for a printing can e.g. be controlled by the control unit. The control unit can e.g. be provided by a microcontroller.

According to the invention, the following steps are performable for each voxel of the surface region and the near surface region. In a first step, a printing material color vector is assignable to the voxel. In a further step, a printing material sequence vector is determinable depending on the printing material color vector. In a further step, one printing material of the printing material sequence vector is selectable depending on a distance of the voxel to its respective closest surface voxel. This distance can also be referred to as voxel depth. In a further step, the selective printing material is assignable to the voxel.

The proposed printing device advantageously allows performing a method according to one of the embodiments described in this disclosure. In particular, one, selected or all steps of said method can be performed by said control unit or a further control unit, e.g. a control unit provided by or being part of a data processing means, e.g. a computer. Thus, the printing device is designed and/or comprises all elements to perform a method according to one of the embodiments described in this disclosure.

In particular, the printing device can comprise more than one, e.g. two or three, means for printing printing materials with different colors and one means for printing the support material.

The invention will be described with reference to the attached Figures. The Figure show:

Figure 1: A schematic block diagram of a 3D color printer,

Figure 2: A schematic representation of printing object voxels and

Figure 3: A schematic flow diagram of a method for 3D color printing.

In the following, corresponding reference numerals denote elements with the same or similar technical features.

Figure 1 shows a schematic representation of a 3-dimensional color printing device 1. The printing device 1 comprises a first print head 2 for printing a first printing material with a first printing material color, e.g. a white color. The printing device further comprises a second print head 3 for printing a second printing material with a second printing material color, e.g. a magenta color. Further, the printing device comprises a third print head 4 for printing a third printing material with a third printing material color, e.g. a cyan color. Further, the printing device 1 comprises a fourth print head 5 for printing a fourth printing material with a fourth printing material color, e.g. a yellow color.

The fourth printing material can be an additional printing material which can be provided by a support material 6. In this case, the fourth printing material color can be equal to a support material color. Support material-related aspects of the following description can, however, also apply to the usage of a fourth printing material (which is not provided by a support material). It is thus possible to use a printing material which is not a support material instead of the described support material 6.

The printing material colors are different from one another. Further shown is a printing object 7 which is T-shaped.

Indicated is a reference coordinate system with a longitudinal axis which is also referred to as X-axis. An arrowhead indicates an X-direction. Further indicated is a vertical axis which is also referred to as Z-axis, wherein an arrowhead indicates a vertical direction. The vertical axis is pointing upwards.

The printing object 7 comprises two over-hanging portions, wherein support material 6 is arranged under these over-hanging portions in order to physically support the construction of the printing object 7. These support material portions can also be referred to as external support material portions 6a. After printing has been finished, these external support material portions can be removed in a removal step, e.g. mechanically or chemically.

Further shown are portions 6b of support material which have been used to construct the printing object 7, in particular interior portions. These portions 6b of support material 6 are arranged in order to provide a desired color reproduction of the printing object 7 or a volume fraction thereof. As these support material portions 6b are interior object portions, they cannot be removed after printing has been finish.

Further shown is that the printing device 1 comprises a control unit 8 for controlling a movement and/or an operation of the print heads 2, 3, 4, 5.

In particular, the print heads 2, 3, 4, 5 which provide means for printing the printing materials can be controlled such that the printing materials are arranged within a surface region and a near surface interior region of the printing object 7 such that a desired color reproduction of the printing object 7 is provided. In other words, the arrangement of printing materials is provided such that a desired coloration of the printing object 7 is provided while a mechanical stability of the printing object 7 is ensured.

Figure 2 shows a region of the printing object 7. Shown are voxels of the printing object 7, wherein these voxels can be provided by printing material.

With reference to the vertical direction, the voxels of the first row (highest row or top row) of voxels are surface voxels of a surface layer voxel set of the printing object 7. The remaining voxels, in particular the voxels within the remaining lower rows, are interior voxels of a near surface interior voxel set of the printing object 7. In particular, the voxels of the second row can be voxels of a first interior layer voxel set, wherein the distances of all voxels of the first interior layer voxel set to the respective closest surface voxel are within a predetermined distance interval, in particular a distance interval ranging from a value corresponding to size of one voxel in the vertical direction to a maximal value corresponding to twice the height of one voxel in the vertical direction. Correspondingly, the voxels of the remaining rows can be voxels of other interior layer voxel sets.

In the embodiment shown in Fig. 2, a layer thickness of the surface layer voxel set and the each of the interior layer voxel sets corresponds to one voxel or the height of one voxel in the vertical direction.

Further, a maximal distance can be predetermined, wherein all voxels of the near surface interior voxel set have a distance to the nearest surface voxel which is smaller than or equal to the maximal distance. In the embodiment shown in Fig. 2, the maximal distance corresponds to 5 voxels or the height of five voxels in the vertical direction.

Further, a total number of layers correspond to the ratio of the maximal distance and the layer thickness. In the embodiment shown in Fig. 2, the total number of layers corresponds to 5.

Further, the distance-to-surface denotes a value which provides the minimum distance of a voxel to the surface according to a given metric. In the embodiment shown in Fig. 2, the nearest surface voxel for the interior voxel V9 is the surface voxel V10.

Further, a layer index can encode the layer to which a voxel belongs. It can be provided by the ratio of the distance-to-surface value and the layer thickness. This ratio can be mapped to the largest integer not greater than the ratio, e.g. by a floor operation, in order to obtain the index of the layer to which the voxel belongs.. In the embodiment shown in Fig. 2, the layer index of the interior voxel V9 is equal to 3, wherein the value of 3 is assigned to the second interior layer voxel set.

The proposed method will be outlined for one of the surface voxels, namely a surface voxel V10 and for one of the interior voxels, namely an interior voxel V9. The proposed method or steps thereof can be performed by the control unit 8 or another control unit (not shown), wherein a control unit can e.g. be provided by a microcontroller.

First, a printing material color is assigned to the surface voxel V10. Depending on the printing material color, a printing material color vector or a reduced printing material color vector can be generated within a modeling step S1 (see Fig. 3), wherein a geometric shape and a coloration of the printing object 7 is defined. The printing material color vector can comprise an entry for each printing material color, wherein a magnitude of the entry is scaled to the interval between 0 (inclusive) to 1 (inclusive). The printing material color vector can comprise an entry for each printing material color except a reference color, wherein a magnitude of the entry is scaled to the interval between 0 (inclusive) to 1 (inclusive).

A reduced printing material color vector for the surface voxel V10 can e.g. be provided by [0.5, 0.5, 0.5], wherein the first entry relates to the second printing material, the second entry relates to the third printing material, and the third entry relates to the fourth printing material. The reduced printing material color vector is transformed to the printing material portion vector that encodes the fraction of printing materials for providing a desired coloration of the printing object 7 at the surface area of the surface voxel 10.

The printing material color vector for a voxel of the near surface interior voxel set can be determined differently. In particular, it is possible that the printing material color vector of the nearest surface voxel is assigned to the respective interior voxel. The nearest surface voxel can be a surface voxel at a distance to the interior voxel which corresponds to the distance-to-empty value of the respective interior voxel. In the embodiment shown in Fig. 2, the printing material color vector for the surface voxel V10 can be assigned to the interior voxel V9.

Second, a printing material sequence vector is determined depending on the printing material color vector. The dimension of the printing material sequence vector corresponds to the total number of layers. In the embodiment shown in Fig. 2, the dimension corresponds to 5. Each entry of the printing material sequence vector corresponds to one printing material.

Third, one printing material of the printing material sequence vector is selected depending on a distance of the voxel to its respective closest surface voxel, e.g. depending on the distance-to-empty value of the corresponding voxel. In particular, the layer index for the corresponding voxel can be determined, wherein the layer index allows determining the printing material within the printing material sequence vector. In particular, the selected printing material can be the printing material at the index of the layer voxel set to which the voxel belongs.

In other words, the printing material at a certain index of the printing material sequence vector is assigned to a voxel of a layer voxel set with the same layer index. If the printing material sequence vector is provided by [M, C, C, Y, W], the printing material with cyan color is assigned to the layer voxel set with the layer index of 2, i.e. the first interior layer voxel set.

Fourth, the selected printing material is assigned to the voxel.

If the printing material sequence vector is provided by [M, C, C, Y, W], the printing material with magenta color will be selected and assigned to the surface voxel V10. Further, the printing material with cyan color will be selected and assigned to the interior voxel V9.

According to a first embodiment, the material sequence vector can be determined by a so-called Halton sequence contoning. In a first sub-step of the Halton sequence contoning, a printing material portion vector is determined depending on the reduced printing material color vector. Determination can comprise a transformation which assigns an o-dimensional printing material portion vector to each reduced printing material color vector, wherein the norm of the printing material portion vector corresponds to 1. This means that entries of the printing material portion vector correspond to portions of one printing material, wherein the magnitude is chosen such that the norm of the printing material portion vector corresponds to 1 and the color reproduction generated by the mixture of the portions corresponds to or differs only minimally form the color reproduction generated by the mixture of the printing material colors according to the printing material color vector.

The dimension of the printing material portion vector can e.g. be equal to the number of all available printing materials. For the embodiment shown in Fig. 1, the dimension of the printing material portion vector is 4.

The transformation can be defined by assigning o-dimensional vectors of unit length to each corner of a printing material color cube which has the dimension of the reduced printing material color vector. Then, a multidimensional interpolation, e.g. a multilinear, in particular a trilinear, interpolation, can be used to determine the printing material portion vector.

If the reduced printing material color vector has entries for the colors cyan, magenta and yellow, a three-dimensional reduced printing material color vector is provided. If, as shown in Fig. 1, four printing materials are available, e.g. cyan, magenta, yellow and white, the resulting printing material portion vector can be determined by interpolating in a three-dimensional cube, wherein each dimension can be handled independently.

For example, the following four-dimensional vectors can be assigned to the corners of the three-dimensional cube: (0, 0, 0, 1), (1, 0, 0, 0), (0, 1, 0, 0), (0, 0, 0.3, 0.7), (0.5, 0.5, 0, 0), (0.7, 0, 0.3, 0), (0, 0.7, 0.3, 0), (0.35, 0.35, 0.3, 0), wherein each vector is defined as (percentage cyan, percentage magenta, percentage yellow, percentage white). Each of these vectors has unit length, e.g. according to the L1-norm.

The transformation, namely the interpolation, can be performed such that the printing material portion vector has unit length as well.

In a second sub-step of the Halton sequence contoning, the number of entries of the printing material sequence vector which are assigned to one of the printing materials are determined depending of the printing material portion vector and the predetermined dimension of the printing material sequence vector. The number of entries of the printing material sequence vector which are assigned to one of the printing materials can also be referred to as number of layers which are occupied by the respective printing material. The numbers of entries assigned to the same printing material sum up to the total number of layers.

First, each entry of the printing material portion vector can be multiplied with the total number of layers. The resulting real number can be rounded to an integer value, e.g. using a randomized threshold. In this case, real numbers with the bigger remaining fractions have a higher chance to be rounded up. However, it is to be ensured that the sum of the rounded number of entries equals to the total number of layers. Further, a material-ordered printing material sequence vector is determined. The material- ordered printing material sequence vector can denote a vector, wherein the sequence of entries is provided by successive subsets of entries which comprise only one printing material.

Further, the first elements of a one-dimensional Halton sequence can be computed, wherein the number of computed elements of the Halton sequence corresponds to the total number of layers. Further, the indices of Halton sequence vector can be reordered in an ascending order of the entries to obtain the transformation of indexes in the sequences. Then, an index of element X in the material-ordered printing material sequence vector can be assigned to the same index of the reordered Halton sequence vector to obtain the index of the reordered

Halton sequence vector which provides the position of the material in the printing material sequence vector.

It is, for instance, possible that the printing materials yellow, cyan, white and magenta are available within a 3D-printing device. If the total number of layers is equal to 5, an exemplary material-ordered printing material sequence vector can correspond to (Y, Y, C, C, W). A reordered printing material sequence vector can then correspond to (C, Y, Y, W, C), wherein, a Halton sequence with the prime number 2 as its base has been used for the reordering.

According to another embodiment, the material sequence vector can be determined by a so-called probability contoning. In a first sub-step of the probability contoning, a cumulative sum of the entries of the printing material portion vector can be computed. If, e.g. the printing material portion vector is provided by (0.1, 0.5, 0.3, 0.1), the cumulative printing material portion vector can be given by (0.1, 0.6, 0.9, 1). Thus, entries of the cumulative printing material portion vector correspond to the sum of the corresponding entry within the printing material portion vector and the preceding entries within the printing material portion vector.

These entries of the cumulative printing material portion can define intervals for each printing material. If the first entry is assigned to the printing material cyan, the second entry is assigned to the printing material magenta, the third entry is assigned to the printing material yellow and the fourth entry is assigned to the printing material white, the interval of 0 (inclusive) to 0.1 (exclusive) is assigned to the printing material with the color cyan, the interval of 0.1 (inclusive) to 0.6 (exclusive) is assigned to the printing material with the color magenta, the interval of 0.6 (inclusive) to 0.9 (exclusive) is assigned to the printing material with the color yellow and the interval of 0.9 (inclusive) to 1 (inclusive) is assigned to the printing material with the color white.

Now, a sequence of random numbers between 0 and 1 can be generated, wherein the sequence has a length equal to the total number of layers. The sequence can e.g. be generated by a so-called Monte Carlo sampling.

Each element of the sequence falls exactly into one of the aforementioned intervals. The printing material sequence vector can be determined by assigning the printing material of the interval to which the random number is assigned to the corresponding entry of the printing material sequence vector. If the total number of layers is e.g. 5, the random number sequence might be (0.7060, 0.0318, 0.2769, 0.0462, 0.0971). As a result, the printing material sequence vector can be provided by (Y, C, M, C, C).

Figure 3 shows a schematic flow diagram of the proposed method. In a first step which is not necessarily part of the claimed method, a CAD-based modelling of the printing object 7 (see e.g. figure 1) is performed. Within this modeling step S1, a geometric shape and a coloration of the printing object 7 is defined. In a compilation step S2, the data encoding the printing object 7 model is compiled in order to generate control data for the control unit 8 (see figure 1) or the print heads 2, 3 ,4 , 5, in particular for an operation and/or movement of the print heads 2, 3, 4, 5.

The modelling data can comprise a printing color vector which comprises one color-related entry per each of the available printing materials or one color-related entry per each of selected, but not all available, printing materials. In this case, the color value of the support material color related-entry can be scaled. In particular, the maximum admissible color value of the support material color-related entry can be limited to a value smaller than the maximum admissible color value of the remaining printing material color-related entries.

Further, a voxelization is performed in the second step.

Within the second step, each voxel within each layer voxel set can be processed voxel-by voxel.

This means that for each voxel of each layer voxel set, a printing material sequence vector is determined according to the aforementioned Halton-sequence-contoning or the probability contoning. Then, one printing material of the printing material sequence vector is selected and assigned to the voxel as described in this disclosure.

It is, for instance possible, to firstly process the voxels of the surface layer voxel set. Then, the voxels of each of the interior layer voxel set can be processed layer-by-layer and voxel-by-voxel. It is, however, also possible to process the voxels of one of the interior layer voxel sets in parallel to the voxels of one, more or all remaining interior layer voxel sets. It is further possible to process the voxels of one or multiple interior layer voxel sets parallel to the voxels of the surface layer voxel set, in particular as soon as a printing material color vector is assigned to the voxels of the surface layer voxel set.

It is further possible to process all voxels of the printing object 7 (see Fig. 1). A reference printing material, e.g. the support material or a printing material with a reference color, e.g. white, can be assigned to voxels which do not belong to the surface layer voxel set or to the near surface interior voxel set. For voxels which belong to the surface layer voxel set or to the near surface interior voxel set, the printing material sequence vector can be determined.

Further, the layer index can be determined, e.g. based on the distance-to-empty value. The printing material which corresponds to the entry with the same index as the layer index of the printing material sequence vector can be selected and assigned to the respective voxel.

In a printing step S3, the printing object 7 is printed by controlling a printing operation, e.g. in form of a disposal of printing material, and movement of the print heads 2, 3, 4, 5 depending on the assignment determined in the second step S2.

It is possible that a layer of the printing object 7 is printed while voxels belonging to a higher layer of the printing object 7 are still processed in the second step S2.

Claims

1. A method for three-dimensional color printing, wherein at least a first printing material with a first printing material color and at least another printing material with another printing material color is used to construct a printing object (7), wherein an arrangement of the printing materials in a surface region and a near surface interior region of the printing object (7) is determined based on a desired color reproduction of the printing object (7),
   characterized in that
   for each voxel of the surface region and the near surface interior region:
   - a printing material color vector is assigned to the voxel,
   - a printing material sequence vector is determined depending on the printing material color vector,
   - one printing material of the printing material sequence vector is selected depending on a distance of the voxel to its respective closest surface voxel,
   - the selected printing material is assigned to the voxel.

2. The method according to claim 1, characterized in that a surface layer voxel set and a near-surface interior voxel set are determined, wherein the surface layer voxel set comprises all surface voxels.

3. The method according to claim 2, characterized in that at least one interior layer voxel set of the printing object is determined, wherein the distances of all voxels of the interior layer voxel set to a respective closest surface voxel are within a predetermined distance interval of non-zero distances, wherein the printing material color vector of the closest surface voxel is assigned to each voxel of the interior layer voxel set.

4. The method according to claim 2 or 3, characterized in that at least one interior layer voxel set of the printing object is determined, wherein the distances of all voxels of the interior layer voxel set to a respective closest surface voxel are within a predetermined distance interval of non-zero distances, wherein an assignment of one of the printing materials to each voxel of the surface layer voxel set is performed independently of an assignment of one of the printing materials to each voxel of the at least one interior layer voxel set and/or wherein an assignment of one of the printing materials to each voxel of one interior layer voxel set is performed independently of an assignment of one of the printing materials to each voxel of at least one other interior layer voxel set.

5. The method according to one of the claims 2 to 4, characterized in that at least one interior layer voxel set of the printing object is determined, wherein the distances of all voxels of the interior layer voxel set to a respective closest surface voxel are within a predetermined distance interval of non-zero distances, wherein an assignment of one of the printing materials to each voxel of one layer voxel set is performed such that distribution of printing materials in said layer voxel set is uncorrelated to the distribution of printing materials in one or each of the remaining layer voxel sets.

6. The method according to one of the claims 1 to 5, characterized in that the printing material sequence vector is determined depending on a printing material portion vector, wherein the printing material portion vector is determined depending on the printing material color vector.

7. The method according to claim 6, characterized in that the printing material portion vector is determined depending on the printing material color vector by an interpolation approach.

8. The method according to claim 6 or 7, characterized in that the number of entries of the printing material sequence vector which are assigned to one of the printing materials are determined depending on the printing material portion vector and the predetermined dimension of the printing material sequence vector, wherein a material-ordered printing material sequence vector is determined.

9. The method according to claim 8, characterized in that for each printing material, a product of the magnitude of the material-specific entry in the printing material portion vector and the dimension of the printing material sequence vector is determined, wherein the number of entries of the printing material sequence vector is determined by rounding the product to the nearest integer value depending on a randomized rounding threshold.

10. The method according to one of the claims 6 to 9, characterized in that the printing material sequence vector is determined such that the probability for selecting one of the printing materials for an entry is similar to the ratio between the magnitude of the material-specific entry in the printing material portion vector and the sum of the magnitudes of all entries in the printing material portion vector.

11. The method according to one of the claims 8 to 10, characterized in that a reordered printing material sequence vector is determined, wherein entries of the material-ordered printing material vector are reordered such that the sequence of reordered entries corresponds to a sequence in which the probability for selecting one of the printing materials for an entry of the printing material sequence vector is similar to the ratio between the magnitude of the material-specific entry in the printing material portion vector and the sum of the magnitudes of all entries in the printing material portion vector.

12. The method according to one of the claims 6 to 10, characterized in that the printing material for one entry of the printing material sequence vector is determined probabilistically, wherein the probability for selecting one of the printing materials for the respective entry is similar to the ratio between the magnitude of the material-specific entry in the printing material portion vector and the sum of the magnitudes of all entries in the printing material portion vector.

13. The method according to one of the claims 1 to 12, characterized in that at least one support material (6) with a support material color is used as an additional printing material, wherein the at least one support material color is selected such that a color gamut (CS) defined by the printing material color(s) is extended.

14. A three-dimensional color printing device, wherein the printing device (1) comprises a means for printing a first printing material with a first printing material color, a means for printing at least one other printing material with another printing material color and at least one control unit (8), wherein the means for printing the first printing material is controlled such that the first printing material is used to construct a printing object (7), wherein the means for printing the at least one other printing material is controlled such that the at least one other printing material is used to construct the printing object (7), wherein
the means for printing the first printing material and the at least one other printing material are controlled such that an arrangement of the printing materials in a surface region and a near surface interior region of the printing object (7) is provided such that a desired color reproduction of the printing object (7) is provided,
characterized in that
for each voxel of the surface region and the near surface region:
- a printing material color vector is assignable to the voxel,
- a printing material sequence vector is determinable depending on the printing material

color vector,

- one printing material of the printing material sequence vector is selectable depending on a distance of the voxel to its respective closest surface voxel,
- the selected printing material is assignable to the voxel.

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Claims searched:	1-14	**Date of search:**	15 January 2016

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
A,E	-	WO 2015/138567 A1 (3D SYSTEMS INC)

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

B29C; B33Y; G06T

The following online and other databases have been used in the preparation of this search report

Online: WPI, EPODOC, XPSPRNG, XPESP, XPIEE, XPI3E

International Classification:

Subclass	Subgroup	Valid From
B29C	0067/00	01/01/2006
G06T	0019/20	01/01/2011
B33Y	0050/02	01/01/2015