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(54) Benævnelse: **FREMGANGSMÅDE TIL DIGITALISERING AF DENTO-MAXILLOFACIALE OBJEKTER**

(56) Fremdragne publikationer:

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US-A1- 2009 212 225
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DESCRIPTION

Field of the Invention

[0001] The present invention relates to a method for capturing the shape of a dento-maxillofacial object out of volumetric image data of that object. Further, the present invention relates to a method for determining a parameter for use in digitizing the dento-maxillofacial object.

Background of the Invention

[0002] Dento-maxillofacial treatments are related to the dentition, the skull and the facial soft tissues. The scope of the treatments goes from handling teeth - such as aligning, restoring crowns, extracting, restoring including root and crown - over bone related treatments - such as maxillofacial surgery involving surgical remodelling or restoring of the skull and dentition, encompassing surgical interventions of repair, in particular, of a mis-positioning of the jaws with respect to one another, called orthognathic surgery, temporomandibular joint (TMJ) treatments - over facial soft tissue treatments - such as tissue sculpting, lifting, ... Important in these treatments is creating a good occlusion and smile line. With 'occlusion' is meant the manner in which the teeth from the upper and lower arches come together when the mouth is closed.

[0003] Since dento-maxillofacial treatments are complex and have a big impact on the patient's facial outlook, accurate treatment planning is required. Computer aided dento-maxillofacial planning systems are becoming available which digitize the traditional manual treatment planning process. In order to be able to optimize the treatment plan, it is often necessary to incorporate in these systems a digitized version of dento-maxillofacial objects, such as dental impressions, dental stone models or removable prostheses etc. Consequently, a need exists to enable accurate digitization of dento-maxillofacial objects.

[0004] Dento-maxillofacial objects, are characterized by a highly irregular shape showing various undercuts and small details. This characteristic makes digitizing the shape a challenging task.

[0005] To digitize dento-maxillofacial objects, surface scanning based on stereo-imaging, structure light imaging, laser scanning or, amongst others, conoscopic holography can be applied. These methods can provide highly detailed surface scans of the objects. Although some techniques are more flexible with respect to the variety of shapes they can scan, certain shapes remain difficult to digitize.

[0006] An alternative method to digitize the shape of the dento-maxillofacial material is using volumetric imaging techniques, such as destructive scanning or tomographic imaging.

Tomographic imaging includes all image modalities that generate tomographic images. These tomographic images can be arranged in a 3D image volume.

[0007] An example of such tomographic imaging is CT scanning. With this modality, X-rays are employed to digitize the shape of the dento-maxillofacial material. This is typically done in an industrialized environment based on industrial CT scanners or micro-CT scanners. However, this approach needs a significant investment, and creates a logistic hassle. For example, a dental impression deforms when it dries. Therefore, it is advisable to digitize the impression as soon as possible and to carefully control the environment in which it is stored.

[0008] Although various imaging techniques exist for scanning objects, the problem remains that capturing the exact contour or the shape of said objects out of the volumetric image data is very difficult or inaccurate. Moreover, this contouring or shaping is usually performed in a subjective manner. This contouring process is often also called segmentation of the volumetric image data.

[0009] Consequently, there is a need for an accurate method to capture the shape out of volumetric image data, such as the shape of dento-maxillofacial materials in a more reliable way.

[0010] In WO00/19929 the volume imaging technique is described of destructive scanning, whereby images of slices are taken.

[0011] Document US 7,123,767 describes techniques for segmenting a digital dentition model into models of individual components using e.g. CT scans. Several 3D segmentation techniques are described, many of which are human-assisted. Other computer-implemented techniques have a drawback that only interproximal margins are created, instead of an accurate threshold value. This document is however not concerned with the accuracy of the segmentation of a digital dentition model, even though this is a crucial factor.

[0012] Publication "Geometric accuracy of digital volume tomography and conventional computed tomography" describes the comparison of the accuracy between digital volume tomographic imaging and with that of conventional CT. A calibration cube with a defined pattern of tubes inside was scanned using CT and digital volume tomography and used to determine the deviation in each image.

[0013] Patent publication EP 1808129 describes a reference device positioned in the mouth which can be used for calibration of distortion at the time of CT imaging.

[0014] US20090212225 discloses a method for positive emission tomography (PET) target image segmentation. The method comprises capturing and digitizing image data of a selected target, determining an initial concentration ratio based on an initial source background ratio and an initial volume estimate of the selected target employing a concentration ratio table, determining a desired threshold from the initial concentration ratio and the initial volume estimate employing a threshold table, and determining a final volume estimate of the selected target based on the determined desired threshold. The concentration ratio table and threshold table are determined in a sphere phantom study investigating and quantifying the relationship between optimal threshold, target volume and target-background concentration ratio.

[0015] There is also a need to offer dental professionals the possibility to scan dento-maxillofacial materials with volume imaging techniques, such as tomographic imaging, that are easily accessible or installed in the dental office. An example of such a tomographic imaging method is CT scanning with a standard medical CT scanner or a Cone-Beam CT scanner.

[0016] Tomographic imaging creates a volumetric image dataset, or even several ones, out of which the surface of the dento-maxillofacial object needs to be segmented. Given the large variety of tomographic imaging equipment, an easy and highly automated method is required in order to allow convenient, accurate digitization of the shape of dento-maxillofacial objects.

Aims of the invention

[0017] The present invention aims to provide a method for generating a digital model of the shape of a dento-maxillofacial object out of a volumetric image data set, whereby the drawbacks and limitations of the prior art are overcome.

Summary of the Invention

[0018] The present invention relates to a method for capturing the shape of a dento-maxillofacial object out of volumetric image data of said dento-maxillofacial object. The method comprises the steps of: a) performing a segmentation of said volumetric image data with at least one calculated segmentation parameter indicative of the distinction between said dento-maxillofacial object and its background, and b) capturing the shape of said dento-maxillofacial object from said segmented volumetric image data. More particularly, the present invention also relates to a method for determining (i.e. calculating) at least one segmentation parameter of volumetric image data of a dento-maxillofacial object, whereby the method comprising the steps of: i) obtaining volumetric image data of a calibration object with the same imaging protocol as used for obtaining said volumetric image data of said dento-maxillofacial object, and ii) determining said at least one segmentation parameter by means of the shape of said calibration object and said volumetric image data of said calibration object. According to the present invention the at least one segmentation parameter is determined by the steps of: a) aligning image data sets of the calibration object and of the volumetric image data of the calibration object, b) deriving a measure for comparing the aligned data sets, and c) deriving the at least one segmentation parameter based on a selection criterion on said measure.

[0019] State-of-the-art methods rely on the intuitive segmentation by the user of the system to obtain a digitization of the material. However, this subjective method implies a big risk related to the correctness of the shape. In the solution according to the present invention, this issue is automatically solved, while keeping the requirement of using readily available equipment to the clinician or dentist, such as a CT scanner.

[0020] In one embodiment said method comprises the step of computing an accuracy measure of the segmentation obtained by applying the at least one segmentation parameter.

[0021] In a specific embodiment the alignment of step a) is performed by voxel-based registration or by a point based alignment method.
In another specific embodiment the selection criterion is based on a histogram that is built by measuring the image values in the volumetric image data of the calibration object at the surface of the aligned calibration object.

[0022] In a preferred embodiment the volumetric image data is obtained by a tomographic imaging technique comprising CT scanning.

[0023] In an embodiment the calibration object has material properties substantially equal to those of the dento-maxillofacial object for a specific imaging technique. In another embodiment the calibration object has shape characteristics substantially equal to the shape of the dento-maxillofacial object. In a further embodiment the calibration object has dimensions substantially equal to the dimensions of the dento-maxillofacial object.

[0024] In another aspect the present invention is related to a method for digitizing a dento-maxillofacial object comprising of the steps of: a) taking a calibration object designed with material properties suitable for a tomographic imaging technique; and optionally substantially equal to the dento-maxillofacial object in both shape and dimensions; b) scanning the calibration object with a tomographic imaging device; c) deriving at least one segmentation parameter; d) scanning the dento-maxillofacial object with the same imaging device and settings as used for the calibration object in step b; and e) applying a segmentation on the scanned dento-maxillofacial object with the at least one segmentation parameter obtained from step c.

[0025] In a preferred embodiment, said segmentation of the method of the present invention is thresholding.

[0026] In yet another aspect the present invention is related to a program, executable on a programmable device containing instructions, which when executed, perform the method as in any of the methods as described above.

[0027] In a further aspect the present invention is related to a kit comprising a calibration object and a data carrier containing the program as described above. In one embodiment said kit further comprises a carrier object for positioning the calibration object in an imaging device, said carrier object imaging significantly different than the calibration object.

[0028] The invention further discloses a method for designing a calibration object.

[0029] A major advantage of the method of the present invention is to correctly, robustly and reliably digitize a material with the equipment readily available to clinicians or dentists. The method guarantees that a detailed and accurate surface is automatically generated given the resolution of the volumetric image volume acquired by the tomographic imaging method.

Brief Description of the Drawings

[0030]

Figure 1 represents a workflow of a digitizing method according to the invention.

Figure 2 represents an outline of the algorithm for defining the optimal threshold value.

Figure 3 represents the calibration object design as scan (a) and produced in polycarbonate (b).

Figure 4 represents (a) the calibration object having a container part and a top part; and (b) the positioning of the top part on the container part.

Figure 5 represents (a) the top and container part filled with the dental impression material; and (b) an impression of the dentitions in the container part after removal of the top part.

Detailed Description of Embodiment(s)

[0031] The term "volumetric scan" means data obtained by a volume imaging technique such as tomographic imaging or destructive scanning. Synonyms used throughout the text are "volumetric image data" or "volumetric image dataset".

[0032] For further storage, processing, design and production of various products in the medical field, accurate digitization of a material reflecting a shape of the body needs to be performed. Since this shape can be highly irregular, imaging the entire shape in one fast acquisition is difficult.

[0033] In the dento-maxillofacial field, various objects are used for this purpose. One family of materials is impression materials. Impressions are made of anatomical parts such as teeth, face, ears. Another family of materials is plaster casts. Plaster models of various anatomical models are typically produced from impressions. Yet other materials, such as prostheses, or especially designed materials, such as radiographic guides and wax-ups, need to be digitized.

[0034] To digitize dento-maxillofacial objects a volumetric imaging technique, such as destructive imaging or tomographic imaging, may be used. In another embodiment surface scanning techniques can be applied.

[0035] A typical tomographic scanning technique uses X-rays. In a clinical or dental environment, scanning with a CT scanner can be used for digitizing the patient's anatomy. The CT scanner can be a medical CT scanner, a cone-beam CT scanner (CBCT) or micro CT scanner (µCT).

[0036] The dento-maxillofacial object reflecting a shape of the body can be positioned on a carrier material that images very different. When the material properties of these two materials are different, the object reflecting a shape of the body can be clearly seen. When the material is scanned, it shows as if it is floating. For imaging using X-rays, very radio-lucent carrier material is good, such as a sponge. However, for the segmentation of the exact shape out of this volumetric scan, given the broad range of equipment present in the medical and dental field, a new step is required, which suits the medical or dental working environment. For this purpose the present invention provides a calibration and segmentation procedure.

[0037] Figure 1 represents a workflow of a method for digitizing an object according to the invention.

[0038] In one embodiment a tomographic scanner (2) is calibrated by performing a scan (4) of a calibration object (3). From this scan one or more segmentation parameters (6) are automatically computed (5). Said calibration object (3) is specifically designed (10) for the object to be digitized (1) with the calibrated tomographic scanner (7). A calibrated segmentation (8) is performed on the scanned material to provide an accurate surface model (9) of said material.

[0039] A calibration object (3) is designed. The material for the calibration object has similar material properties for the tomographic imaging method as the target material that needs to be digitized. The exact shape information (10), which can be similar to the shape of the real material that needs to be digitized, is known by design.

[0040] The calibration object is scanned in the same way and with the same scanner as the target material is scanned (4). Based on the volumetric image data from the scan (11) and the known shape from the design (10), the parameters that generate the exact shape for a specific segmentation approach (6) are determined (5). With these parameters, the binary decision point where the exact shape of the scanned object is located is determined. In addition to this, an accuracy measure of the resulting segmentation can be computed (12).

[0041] Now, the actual material is scanned with the same scan protocol as the calibration scan (7). The segmentation algorithm is applied (8) with the determined parameters (6). In this way the exact shape of the material is obtained (9).

[0042] The calibration scan can easily be redone with a regular frequency in time, or when changes or updates to the CT-scanning equipment, or to the materials used, occur. This method is fast and can be handled by the clinicians and their team themselves.

[0043] In a specific embodiment segmentation of a surface out of a volumetric image volume is performed by thresholding. A threshold value defines the transition between the material and background, and hence the surface of the material.

[0044] Figure 2 illustrates an algorithm for automatically computing the optimal threshold value or segmentation parameters (5).

[0045] The algorithm requires two input data sets: the calibration object design (10) and the image volume(s) of the calibration object (11). The algorithm consists of three major steps: aligning the two input data sets (13-14), building a histogram (15-16) and finally deriving the optimal threshold value (17-20), i.e. the value of the segmentation parameter.

[0046] Since the calibration object design (10) and the image volume (11) are not aligned an alignment step is required. Aligning is defined as searching a transformation so that the transformed object and the image volume share the same 3D space, and thus coincide. To obtain this alignment different procedures can be used. A possible approach is as follows. First, an image volume based on the calibration object design (10) is computed. Next this image volume is aligned with the image volume of the calibration object obtained through tomographic imaging (11). The outcome of this algorithm is a transformation which is then applied to the calibration object design (10) to obtain an aligned calibration object design (14). The aligned calibration object design (14) coincides with the image volume of the calibration object (11) in the same 3D space.

[0047] In one embodiment the alignment can be done by voxel-based registration based on maximization of mutual information (IEEE Transactions on Medical Imaging, 16(2):187-198, April 1997). In another embodiment a point based alignment method (IEEE Transactions on Pattern Analysis and Machine Intelligence, 9(5), September 1987) is used. This point based alignment method first extracts well definable points or features on the calibration object design (10) and in the image volume of the calibration object (11). Next the method searches the transformation which aligns the corresponding 3D points of both data sets.

[0048] In a second step, the algorithm measures the image values in the image volume of the calibration object (11) at the surface of the aligned calibration object design (14). All measured image values are stored and a histogram of the stored image values (15) is built. To improve the stability of the algorithm the measure area can be extended towards a small region around the surface of the aligned calibration object design (14). In this way noise in the alignment algorithm or in the scanned data can be partially eliminated.

[0049] At last the optimal threshold value (19), in other words the segmentation parameter, is derived (17) by using a selection criterion (18) in combination with the generated image values

histogram (16). Possible selection criteria (18) are: mean image value, most frequent image value, maximum image value, etc. Different selection criteria may result in slightly different threshold values and the optimal selection criterion is dependent on the final application.
After defining an optimal threshold value a measure of the to-be-expected overall accuracy (20) of the segmentation can be obtained. To calculate this value a surface representation is generated out of the scanned image volume of the calibration object (11) using a marching cubes algorithm (Proc. of SIGGRAPH, pp.163-169, 1987) and the derived optimal threshold value. Next a distance map between this surface representation and the calibration object design (10) can be calculated. This distance map or any statistical derived measure from this distance map represents the to-be-expected accuracy of the overall digitization procedure for the material to be digitized given the tomographic imaging method and equipment with the according imaging protocol.

[0050] An alternative method for automatically computing the optimal threshold value comprises the steps of aligning the scanned calibration object and the virtual calibration object design, generating for any threshold value a distance map between the reconstructed surface of the scanned object and the virtual surface of the object design and deriving the optimal threshold value based on the calculated distance maps.

Example 1: Design of calibration object (10) for acrylic prosthesis

[0051] In case the material to be digitized (1) is an acrylic dental prosthesis, some specific guidelines can be considered when designing the calibration object (10). First, the volume of the designed object is preferably more or less equal to the volume of a typical dental prosthesis. Moreover it is preferred that the surface of the object contains sufficient detailed 3D information, i.e. shape variation, so that the accuracy of the algorithm can be guaranteed. Finally the properties of the material used for the calibration object should be similar or equal to those of the material to be digitized for the specific tomographic imaging technique.

[0052] In case the tomographic imaging method is CT scanning for said acrylic prosthesis, the calibration object (10) can be designed as follows. The calibration object consists of a typical dental surface virtually mounted on a cylinder with a small height. The designed object is produced in polycarbonate which has similar radio-opacity characteristics as the acrylic materials used for producing dental prostheses (Figure 3). An example of such polycarbonate is TECANAT™.

Example 2: Design of calibration object (10) for a dental impression

[0053] In case the material to be digitized is a dental impression and the tomographic imaging method is CT scanning, some specific guidelines can be considered when designing the calibration object (10). First, it should be noted that many dental impression materials exist. All these materials have different radio-opacity characteristics. Therefore the designed calibration object should be usable for any of these dental impression materials. Second, it is preferred that the volume of the calibration object is more or less equal to the volume of a typical dental impression. Finally the calibration object preferably includes sufficient detailed 3D information, i.e. shape variation, so that the accuracy of the algorithm can be guaranteed. To meet these guidelines a calibration object can be produced and a special calibration procedure can be elaborated.

[0054] An embodiment of a specific design is as follows. In a specific embodiment, and as shown in Figure 4, the designed object (10) consists of two parts: a top part and a container part. The top part is a cubic shaped block with at the lower side a structure which resembles the upper dentition. The container part consists of two cavities. The size of the first cavity (C1 in Fig.4b) is slightly larger than the top part. The second cavity (C2 in Fig.4b) is slightly smaller than the top part. Due to the different sizes of the two cavities the top part can be placed on top of the container part in a well known position. To calibrate the impression material, the lower cavity C1 is filled with the impression material (see Fig.4b). Next the top part is placed on the container and the two parts are pushed into tight contact with each other. After a few minutes when the impression material has hardened, the top part can be removed. The remaining part, i.e. the container part with the impression material, defines the final calibration object which will be scanned to obtain the image volume of the calibration object (11). The dentition surface at the lower side of the top part serves as the calibration object design (10).

[0055] Although the present invention has been illustrated by reference to specific embodiments, it will be apparent to those skilled in the art that the invention is not limited to the details of the foregoing illustrative embodiments It will furthermore be understood by the reader of this patent application that the words "comprising" or "comprise" do not exclude other elements or steps, that the words "a" or "an" do not exclude a plurality, and that a single element, such as a computer system, a processor, or another integrated unit may fulfil the functions of several means recited in the claims. Any reference signs in the claims shall not be construed as limiting the respective claims concerned. The terms "first", "second", third", "a", "b", "c", and the like, when used in the description or in the claims are introduced to distinguish between similar elements or steps and are not necessarily describing a sequential or chronological order. Similarly, the terms "top", "bottom", "over", "under", and the like are introduced for descriptive purposes and not necessarily to denote relative positions.

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- WO0019929A [0010]
- US7123767B [0011]
- EP1808129A [0013]
- US20090212225A [0014]

Non-patent literature cited in the description

- IEEE Transactions on Medical Imaging, 1997, vol. 16, 2187-198 [0047]
- IEEE Transactions on Pattern Analysis and Machine Intelligence, 1987, vol. 9, 5 [0047]
- Proc. of SIGGRAPH, 1987, 163-169 [0049]

Patentkrav

1. Fremgangsmåde til bestemmelse af mindst én segmenteringsparameter for volumetriske billeddata for et dento-maxillofacialt objekt, hvilken fremgangsmåde omfatter følgende trin:

i. opnåelse af volumetriske billeddata (11) for et kalibreringsobjekt (3) med en given form med den samme billeddannelsesprotokol, som anvendes til opnåelse af de volumetriske billeddata for det dento-maxillofaciale objekt;

ii. bestemmelse af den mindst ene segmenteringsparameter (6), idet der tages højde for kalibreringsobjektets (3) form og de volumetriske billeddata (11) for kalibreringsobjektet (3);

kendetegnet ved, at den mindst ene segmenteringsparameter (6) bestemmes ved hjælp af følgende trin:

a. opstilling af billeddatasæt for kalibreringsobjektets (10) form og for de volumetriske billeddata for kalibreringsobjektet (3);

b. udledning af et mål til sammenligning af de opstillede datasæt;

c. udledning af den mindst ene segmenteringsparameter (6) under anvendelse af et udvælgelseskriterium på målet.

2. Fremgangsmåde ifølge krav 1, der omfatter det trin, at der beregnes et nøjagtighedsmål (12) for en segmentering opnået ved anvendelse af den mindst ene segmenteringsparameter (6).

3. Fremgangsmåde ifølge kravene 1 eller 2, hvor opstillingstrinnet udføres ved voxelbaseret registrering eller ved en punktbaseret opstillingsfremgangsmåde.

4. Fremgangsmåde ifølge et hvilket som helst af kravene 1 til 3, hvor udvælgelseskriteriet er baseret på et histogram, der opbygges ved måling af billedværdier i de volumetriske billeddata for kalibreringsobjektet (11) ved overfladen af det opstillede kalibreringsobjekt (14).

5. Fremgangsmåde ifølge et hvilket som helst af de foregående krav, hvor de volumetriske billeddata opnås ved hjælp af en tomografisk billeddannelsesteknik, der omfatter CT-scanning.

6. Fremgangsmåde ifølge et hvilket som helst af kravene 1 til 5, hvor kalibreringsobjektet (3) har materialeegenskaber, som i det væsentlige er lig med egenskaberne hos det dento-maxillofaciale objekt til billeddannelsesprotokollen.

7. Fremgangsmåde ifølge et hvilket som helst af kravene 1 til 6, hvor kalibreringsobjektet (3) har en form, som i det væsentlige er lig med det dento-maxillofaciale objekts form.

8. Fremgangsmåde ifølge et hvilket som helst af kravene 1 til 7, hvor kalibreringsobjektet (3) har dimensioner, som i det væsentlige er lig med det dento-maxillofaciale objekts dimensioner.

9. Fremgangsmåde til digitalisering af et dento-maxillofacialt objekt, hvilken fremgangsmåde omfatter følgende trin:

a. der tages et kalibreringsobjekt (3) udformet med materialeegenskaber, der er egnet til en tomografisk billeddannelsesteknik; og valgfrit i det væsentlige lig med det dento-maxillofaciale objekt i både form og dimensioner;

b. kalibreringsobjektet (13) scannes med en tomografisk billeddannelsesindretning;

c. der udledes mindst én segmenteringsparameter (6) ifølge krav 1;

d. det dento-maxillofaciale objekt scannes med den samme billeddannelsesindretning og de samme indstillinger, som anvendes til kalibreringsobjektet (3) i trin b;

e. der anvendes en segmentering på det scannede dento-maxillofaciale objekt med den mindst ene segmenteringsparameter (6), som blev opnået i trin c.

10. Fremgangsmåde ifølge et hvilket som helst af de foregående krav, hvor segmenteringen er threshold-billedbehandling.

11. Fremgangsmåde til fastholdelse af et dento-maxillofacialt objekts form ud fra volumetriske billeddata (11) for det dento-maxillofaciale objekt, hvilken fremgangsmåde omfatter følgende trin
a. der udføres en segmentering af de volumetriske billeddata (11) med mindst én beregnet segmenteringsparameter (6), der blev opnået ifølge krav 1, og som indikerer forskellen mellem det dento-maxillofaciale objekt og baggrunden, og
b. det dento-maxillofaciale objekts form fastholdes ud fra de segmenterede volumetriske billeddata (11).

12. Program, der kan afvikles på en programmerbar indretning, som indeholder instruktioner, der ved afvikling udfører fremgangsmåden ifølge et hvilket som helst af kravene 1 til 10.

13. Kit, der omfatter et kalibreringsobjekt (3) og en databærer, som indeholder programmet ifølge krav 12.

14. Kit ifølge krav 13, der endvidere omfatter et objekt til positionering af kalibreringsobjektet (3) i en billeddannelsesindretning, hvilket objekt danner billeder signifikant anderledes end kalibreringsobjektet (3).

DRAWINGS

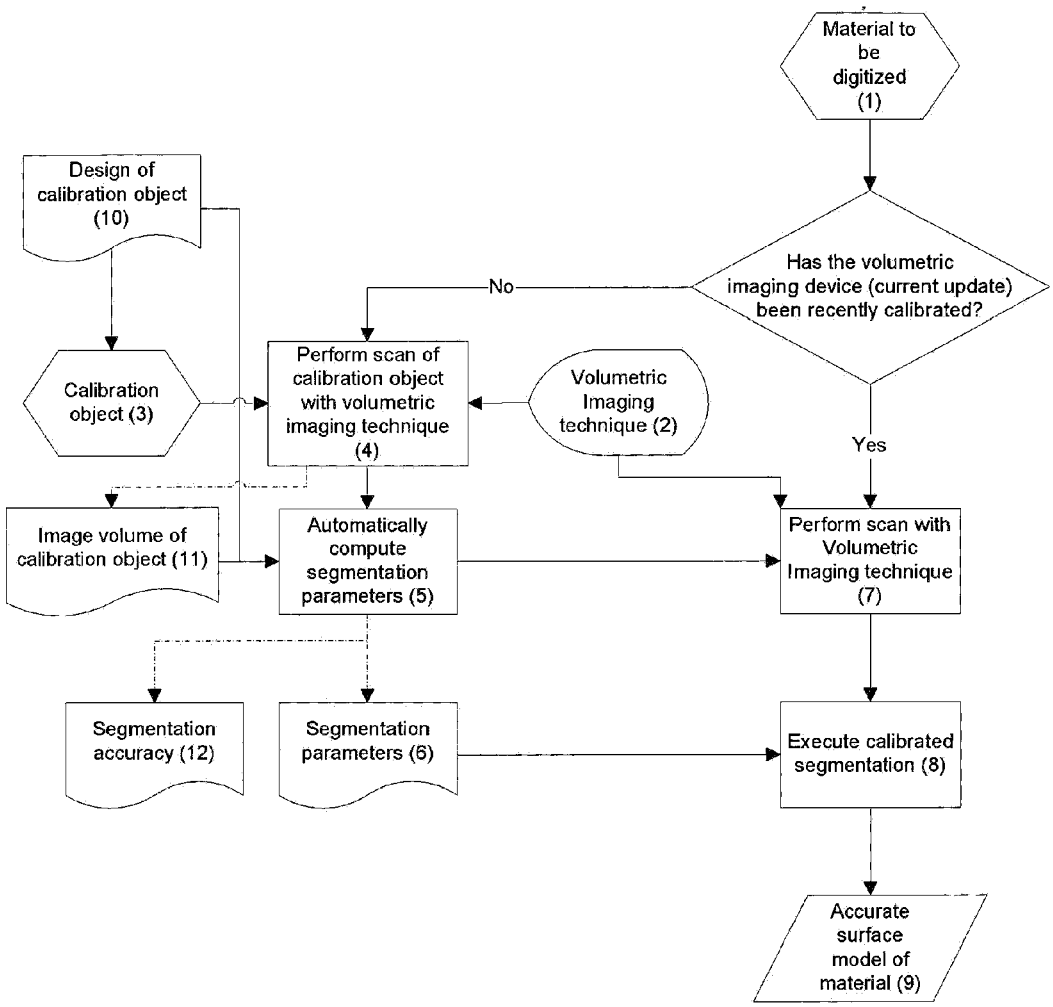


Figure 1

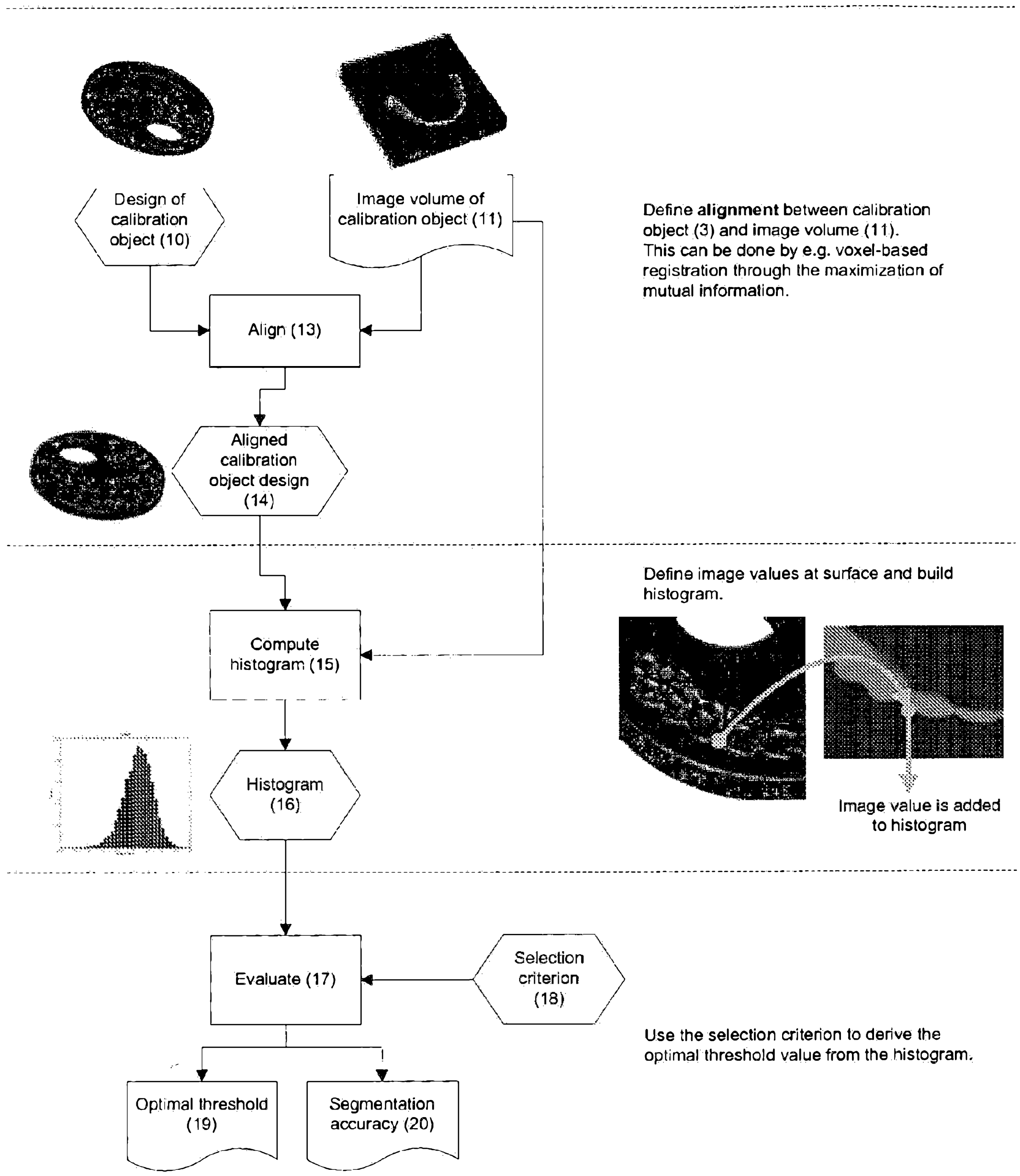
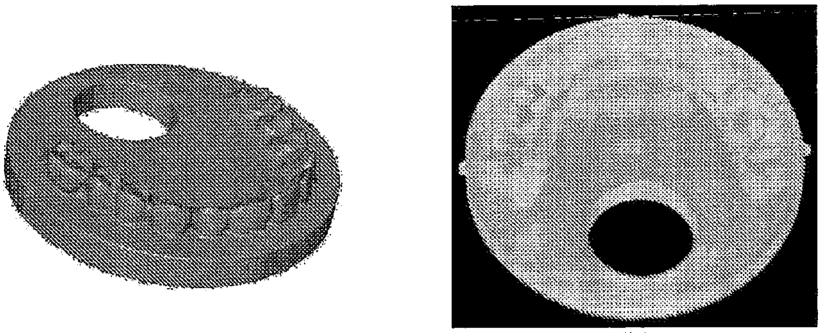
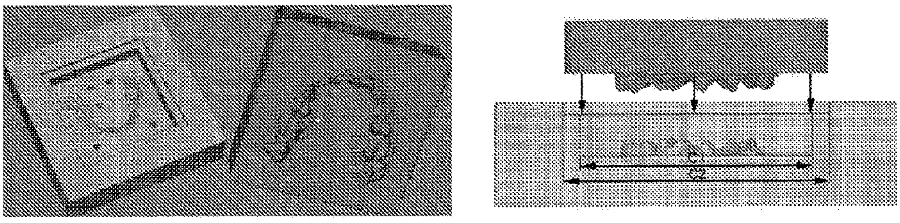

Design of calibration object (10)
Image volume of calibration object (11)
Define alignment between calibration object (3) and image volume (11). This can be done by e.g. voxel-based registration through the maximization of mutual information.
Align (13)
Aligned calibration object design (14)
Define image values at surface and build histogram.
Compute histogram (15)
Histogram (16)
Image value is added to histogram
Evaluate (17)
Selection criterion (18)
Use the selection criterion to derive the optimal threshold value from the histogram.
Optimal threshold (19)
Segmentation accuracy (20)

Figure 2



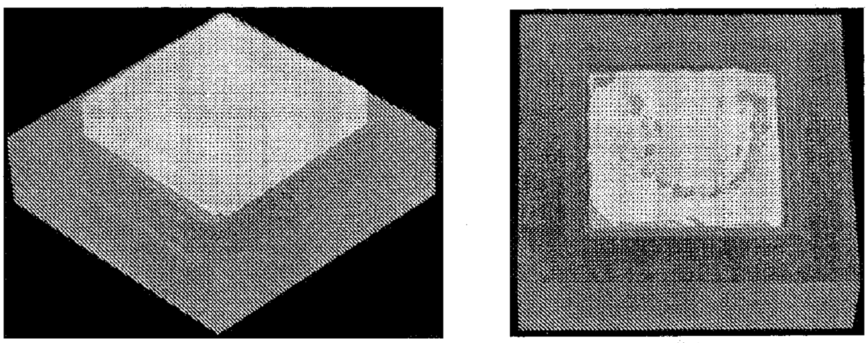
(a) (b)

Figure 3



(a) (b)

Figure 4



(a) (b)

Figure 5