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- (72) **Inventors; and**
- (71) **Applicants :** UCCHEDDU, Francesca [IT/IT]; Via Al-
lori, 73, I-50127 Firenze (IT). PELAGOTTI, Anna
[IT/IT]; Via dell'albero, 9, I-50123 Firenze (IT).
- (74) **Agent:** NESTI, Antonio; Studio Ferrario S.r.l., Via del
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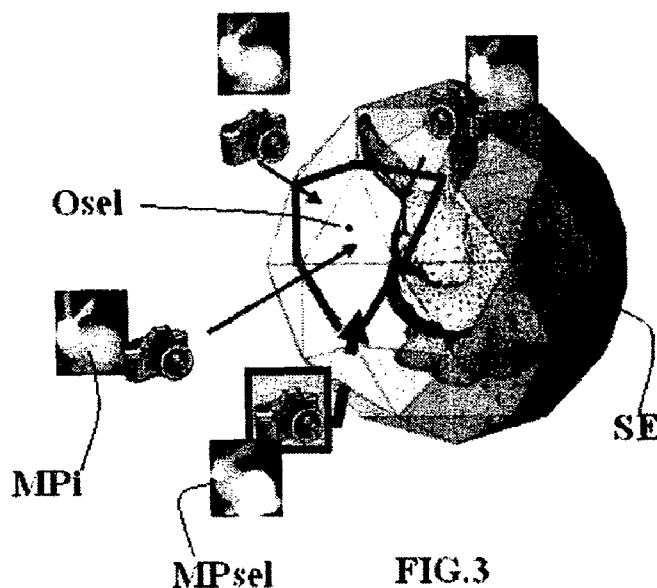
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(54) **Title:** METHOD AND APPARATUS FOR TEXTURING THREE-DIMENSIONAL MODELS WITH TWO-DIMENSIONAL IMAGES



(57) **Abstract:** A method for texturing a three-dimensional digital model (M) of an object, made up of points in space (Pxyz) with a two-dimensional digital input image (I) comprising the steps of constructing two-dimensional images (MPI) obtained by projecting the points (Pxyz) of the model (M) in a plane (Li), establishing a relation of maximum resemblance between the input image with one of the images constructed (3D image), and reiterating said steps until a constructed two-dimensional image of the model is determined in direct vertex-pixel correspondence with the digital input image (I) .

**METHOD AND APPARATUS FOR TEXTURING THREE-DIMENSIONAL MODELS
WITH TWO-DIMENSIONAL IMAGES**

Technical sector

5 The invention relates to a method and an apparatus for texturing three-dimensional digital models with digital images of different origin, i.e., photographic, radiographic, etc.

In the present exposition, by "texturing of a 3D model" is
10 meant mapping of the surface of the model with a two-dimensional image.

Prior art

Methods for creating 3D digital models of an object, obtained starting from the collection of data by means of
15 sensors for a wide range of applications, have been known for some time. The 3D models, once created, must be "textured" i.e., mapped with two-dimensional digital images of the object to improve their adhesion to reality.

In many cases, the two-dimensional images may be images of
20 a photographic type, but according to the purpose to be achieved may also be radiological images, thermographic images, etc.

Texturing basically consists of the combination of the points of internal and/or external surfaces of the 3D model
25 with corresponding points of the image to be textured.

Generally, starting from a 3D model and photographic images of one and the same object, the texturing process entails mapping of information of colour "carried" by the photographic image onto the points of the 3D surface, or
30 onto the elements (generally triangles) of a mesh representing the 3D surface.

With methods of a known type, if there is no complete information on the position of the sensors used for detecting the modelled object, it is not possible to render

association between the points of the 3D surface and the homologous points of the image to be textured automatic.

But for each (photographic, radiological, etc.) image to be textured there must be set up the relation between the 3D
5 image and the 2D image to obtain a homogeneous point-by-point combination.

As a consequence, in the current state of the art, to texture a generic digital 3D model of an object with 2D digital images of the same object, even of different
10 origin, intermediate manual or semi-manual steps are necessary.

Purpose of the invention

The purpose of the present invention is to overcome the drawbacks of known technologies and to propose a method and
15 an apparatus for texturing 3D digital models of an object with 2D digital images of the same object, which will achieve a high level of correspondence and will be implementable in an even completely automatic way.

Summary of the invention

20 The above purpose has been accomplished according to the invention with a method and an apparatus according to one or more of the annexed claims.

The advantages achieved consist in the complete automation of the texturing process, irrespective of the knowledge of
25 the optical sensors used for digital acquisition of the 3D model and of the type of 2D image to be textured, and in general when it is not possible to acquire the image to be textured and the model simultaneously.

Specific advantages are obtained in many spheres of application when it is required to texture a model with
30 images obtained with different sensors, such as multispectral/multimodal views (infrared, x-ray, UV fluorescence), or with images taken at different moments, such as, for example, in the case of works of art, before

or after restoration or, in the case of surgery, before and after a surgical operation.

A further advantage is represented by the capacity of the method to establish a real and precise correspondence
5 between the image to be textured and the 3D model. Specific advantages are those deriving from the possibility of automation, with saving in time and reproducibility of the results. This is particularly useful in the case of maps of extensive surfaces, such as towns that can be textured with
10 multiple views, having available images of small portions.

List of the drawings

The above and further advantages will be better understood from the ensuing description and from the annexed drawings, which are provided by way of non-limiting examples of the
15 invention and in which:

- Figure 1 shows an example of point of observation for the creation of a depth map of a model, with respect to a reference plane;
- Figures 2-4 show an example of subsequent selection of
20 observation points, according to the method of the invention;
- Figure 5 shows the two-dimensional images of the depth maps obtained in the first iteration of the algorithm for selection of the observation points, and the
25 respective value of resemblance with the image to be textured, expressed as value of maximum mutual information (MMI);
- Figure 6 shows the difference image between the preferred depth map and the external image to be
30 textured;
- Figure 7 shows the two-dimensional images of the depth maps obtained in a subsequent iteration of the algorithm for selection of the observation points, and

the respective value of resemblance with the image to be textured, expressed as value of maximum mutual information (MMI);

5 - Figure 8 shows the difference image between the preferred depth map and the external image to be textured in two successive iterations of the selection step;

10 - Figure 9 shows a model textured with the method according to the invention, where the blank parts are parts not covered by the external image used and hence not mapped;

- Figure 10 shows a second example of 3D model and an external image to be textured on the model;

15 - Figure 11 shows in the first row the depth maps of the model of Figure 10, selected in three successive iterations according to the method and in the second row the difference images with the image to be textured;

20 - Figure 12 shows the 3D model of Figure 10 textured with the method according to the invention starting from the external image chosen.

Described with reference to the drawings is a method according to the invention for automatic texturing of a digital model M in three dimensions of an object S with
25 external two-dimensional digital images I of the same object, even acquired independently of the creation of the model, for example photographic images, or radiological images, or images of another type.

According to the method, around the model M there is
30 ideally created an outer surface IF, on which a finite number of observation points Oi of the model are established, preferably distributed in an equidistant manner in order to cover the entire surface on a regular

polyhedron (for example, an icosahedron).

Starting from each viewpoint, a two-dimensional image MP is created, obtained by projecting the points Pxyz of the surface of the model M in a plane Li constructed as a function of the observation point Oi, in such a way as to be able to identify the pixels of the image MP in direct correspondence with points Pxyz of the model M (Figure 1), and in such a way that the pixels of the two-dimensional images MP of the model M contain information regarding the distance between the corresponding points Pxyz of the model M and the pre-selected plane of projection Li.

Having created various two-dimensional images MPi (Figure 5) that cover the surface to be investigated of the model, a measurement of maximum resemblance is established between the external two-dimensional image I of the object S and one of the two-dimensional images MPsel of the model selected on the basis of criteria of maximum resemblance, for example the value of the maximum mutual information (MMI) between the two two-dimensional images (Figure 6).

The image selected MPsel thus corresponds to a selected observation point Osel .

Preferably, the outer surface is assumed as a regular polyhedron constituted by faces of which the observation points represent the central point. In this case, the selected observation point Osel will be the central point of the face of the polyhedron to which the selected image MPsel corresponds (Figure 2).

Once identified the point Osel and the corresponding face of the surface IF, it is possible to re-iterate creation of further observation points of the model in an area of the surface IF comprising the neighbourhood of said point Osel, obtaining a higher resolution, i.e., observation points closer to the points established previously (Figures 3-4), and to re-iterate the search for the relation of maximum

resemblance until a subsequent preferred two-dimensional image of the model is determined.

The procedure can be re-iterated until a preferred two-dimensional image (MPpref) is determined that meets a pre-set criterion of acceptance of resemblance with the external image I.

Thanks to the method according to the invention, the points of the image MPpref have by construction a point-by-point correspondence with the surface of the model and have at the same time a strict correlation with the digital input image I, which increases as the number of automatic iterations increases (Figures 7-8) until the pre-set criterion of acceptability is met.

Preferably, the two-dimensional images of the model M are constructed as depth maps, where the level of grey of the pixels of the image represents the distance of the corresponding point Pxyz of the investigated surface of the model M from the plane Li of projection.

In greater detail, in the method according to the invention the depth maps are constructed starting from the model M, as a two-dimensional array, so that the co-ordinates x, y of the points of the model correspond to the rows and the columns of the matrix (as in an ordinary image), whilst the corresponding values of depth (value z of the points of the model) refer to a plane of section of the model (or an external plane) and are stored in the value of the element of the array. Said map is then constructed as a grey-scale image in which the information z is stored in the intensity-of-grey information. The images MP are hence a projection of appropriate surfaces of the model M in the two-dimensional plane Li.

Advantageously, the maps MP constructed in this way thus intrinsically maintain an exact correspondence between the 2D pixels and the 3D points of the model.

- At the end of the process, there is consequently obtained an exact correspondence between the pixels of the constructed image MP and of the image to be textured I and at the same time to each point Pxyz of the model M there
- 5 can be associated a corresponding pixel of the image MP.
- As a result, it is possible to associate automatically, to each point of the model, a colour of a corresponding pixel of the external image I and a bit of information of depth with respect to a plane of projection.
- 10 Also the step of selection of the "best" image MP_{pref} can be executed automatically, for example, as has been said, by entering a predefined value of measurement of resemblance, such as the mutual information itself or other recording methods.
- 15 As emerges clearly from what has been said, the method is suited for automatic execution via a computer program appropriately instructed with the initial pre-selected data, i.e., the model M to be textured, the image or images I of the subject S, acquired even at different times and/or
- 20 with different techniques, and an initial ensemble of preferences (number and distribution of the observation points O_i, choice of the plane of projection L_i, number of iterations or criteria of resemblance threshold in recording the 2D-2D images.
- 25 The present invention has been described according to preferred embodiments, but equivalent variants can be devised without thereby departing from the sphere of protection of the invention.

CLAIMS

1. A method for texturing a three-dimensional digital model (M) of an object made up of points in space (Pxyz) with a two-dimensional digital input image (I) of the object, **characterized in that** it comprises the following steps:

- establishing a finite number of observation points (Oi) of the model (M), which are equidistant and distributed for covering the outer surface (IF) containing the model (M) of the object;

- constructing for each viewpoint a two-dimensional image (MPi) obtained by projecting the points (Pxyz) of the model (M) in a plane (Li) constructed as a function of the observation point (Oi) in order to identify pixels of the image (MPi) in direct correspondence with points (Pxyz,i) of the model;

- establishing a relation of maximum resemblance between said two-dimensional image (I) of the object with one of the two-dimensional images (MPi) of the model and selecting a first image (MPsel) with maximum resemblance, corresponding to a selected observation point (Osel); and

- reiterating said creation of further finite numbers of observation points (Oi) of the model (M), with higher resolution with respect to the finite number of points established previously, in an area of the surface (IF) comprising the neighbourhood of said point (Osel), and reiterating said relation of maximum resemblance until a two-dimensional image of the preferred model (MPpref) is determined in point-by-point correspondence with the digital input image (I),

wherein the pixels of said two-dimensional images (MPi) of the model (M) contain information regarding the distance between the corresponding points (Pxyz) of the model (M) and the plane of projection (Li).

2. The method according to Claim 1, wherein said outer surface is a polyhedron containing the model (M).
3. The method according to Claim 2, wherein said observation points (O_i) are chosen as central points of corresponding faces of said polyhedron containing the model (M).
4. The method according to any one of the preceding claims, wherein said relation of resemblance is determined by the value of the maximum mutual information.
5. The method according to any one of the preceding claims, comprising a further step of association to each point (P_{xyz}) of the model (M) of a numerical value, corresponding to the colour or to a grey-scale value associated to the corresponding pixel of the two-dimensional input image (I).
6. The method according to any one of the preceding claims, wherein said information of the pixels of the two-dimensional image (MP) regarding the distance between the corresponding points (P_{xyz}) of the model and the plane of projection (L_i) comprise a level of grey.
7. The method according to any one of the preceding claims, wherein said external image is obtained with a sensor selected from among sensors in the visible, infrared, x-ray, UV fluorescence.
8. The method according to any one of the preceding claims, comprising the preliminary steps of acquiring a two-dimensional digital input image (I) of the object and creating a three-dimensional digital model (M) of the object.
9. A computer program, for implementing automatically a texturing method according to any one of the preceding claims.
10. An apparatus comprising a memory containing a program according to Claim 9 and an electronic processing unit for running the program.

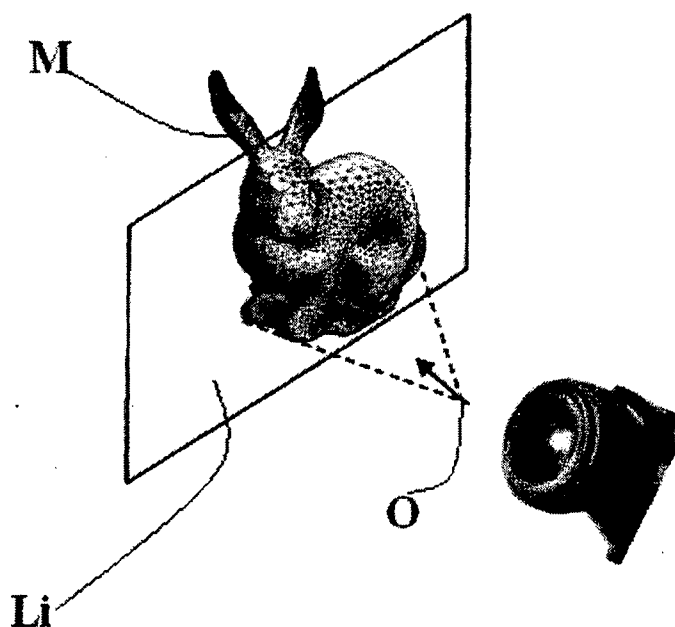


FIG.1

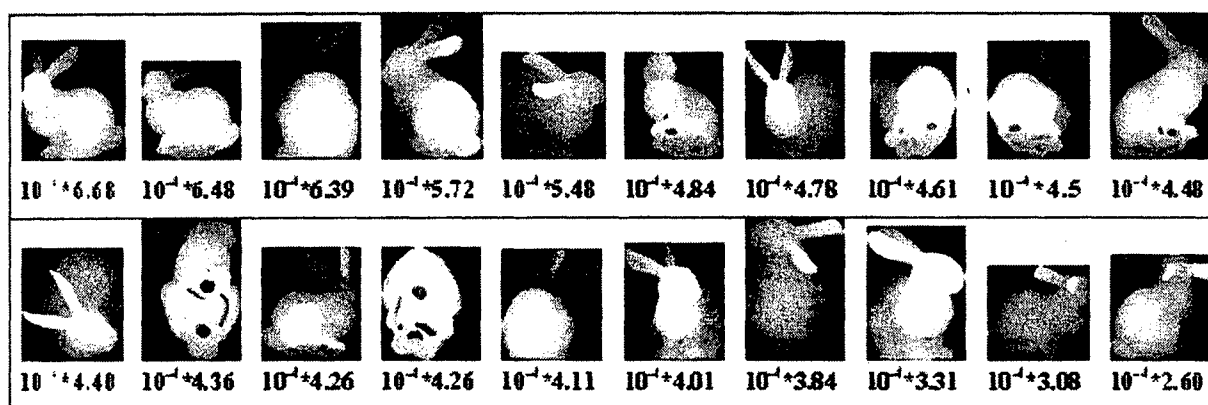
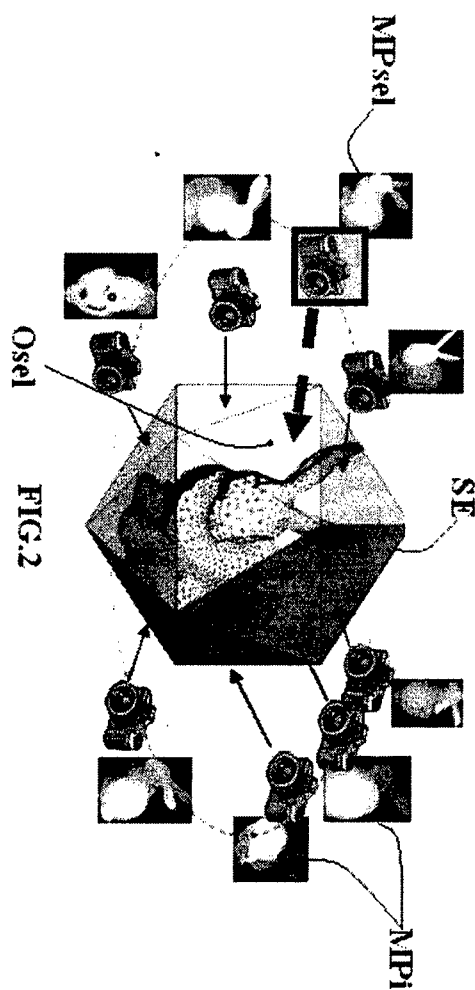
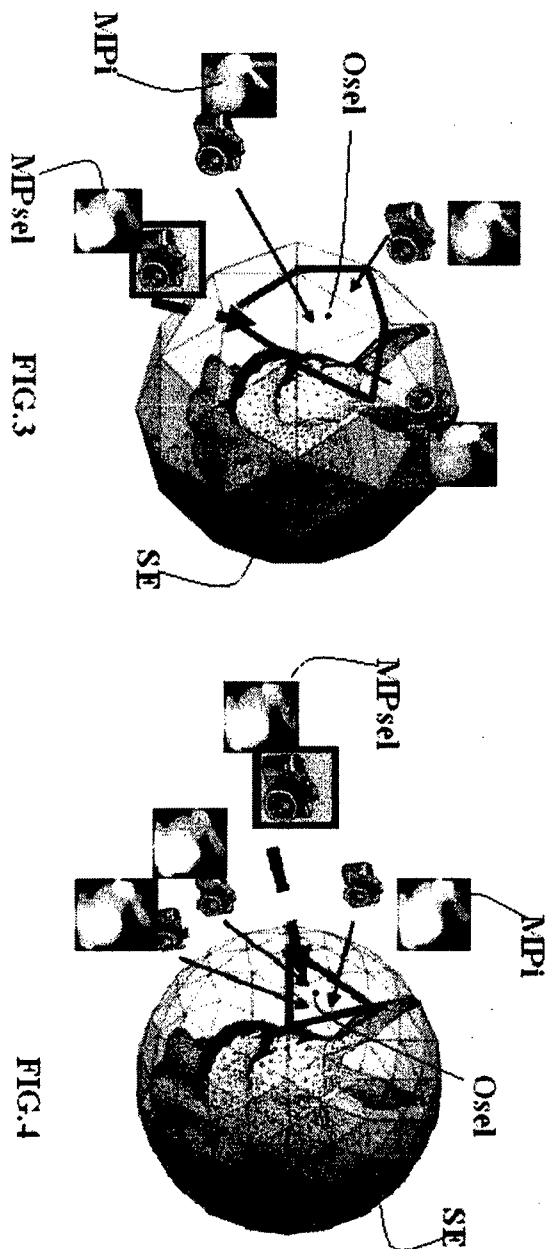


FIG.5



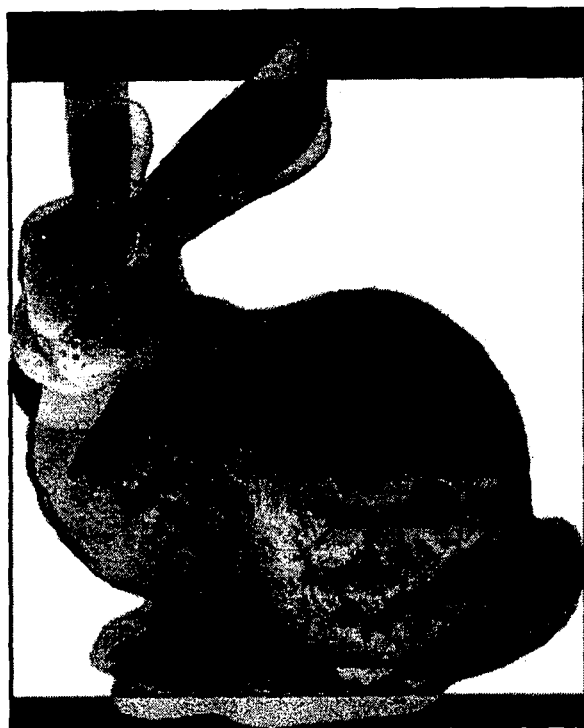


FIG.6

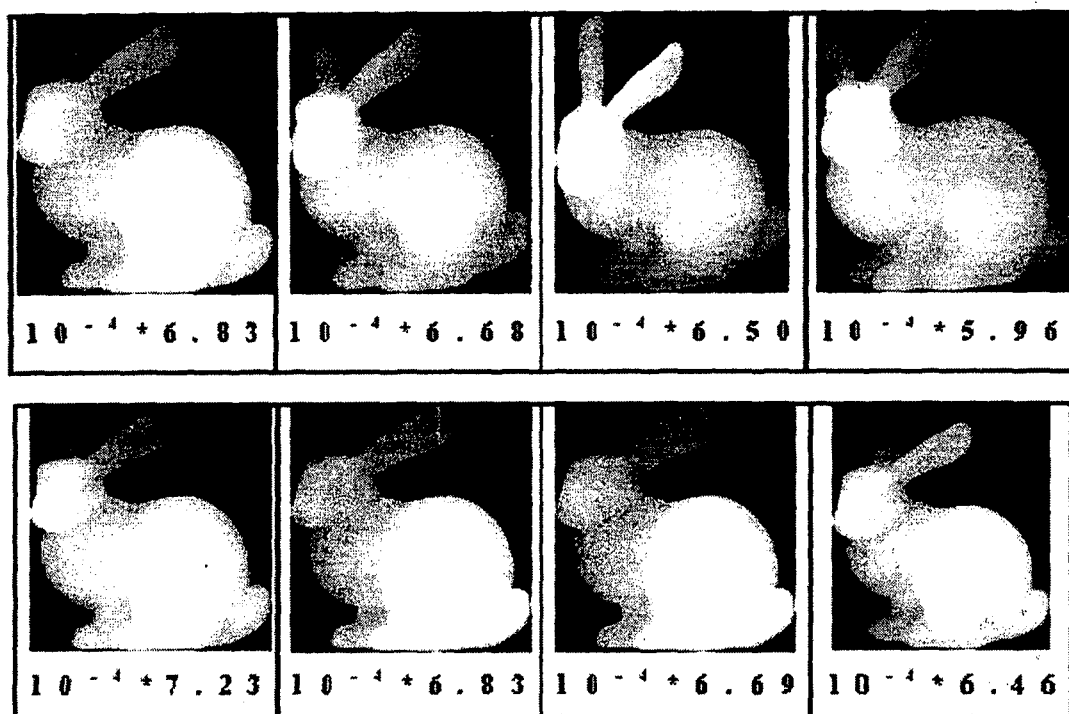


FIG.7

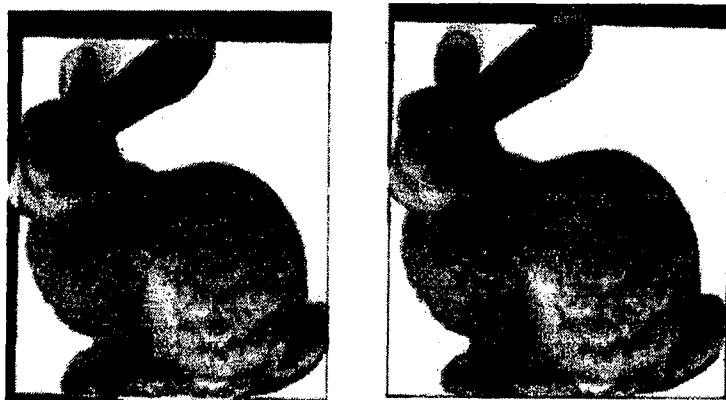


FIG.8



FIG.9



FIG.10

M

I

MPsel

MP.pref

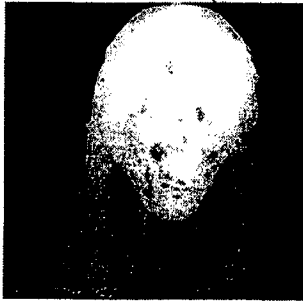


FIG.11





FIG.12

INTERNATIONAL SEARCH REPORT

International application No
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A. CLASSIFICATION OF SUBJECT MATTER

INV. G06T15/20 G06T15/04
ADD. G06T17/00

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G06T G06F G06K

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

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

EPO-Internal, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>REMONDINO F ET AL: "Novel data registration techniques for art diagnostics and 3D heritage visualization", PROC. OF IX CONF. ON OPTICAL 3-D MEASUREMENT TECHNIQUES, vol. 1, 1 July 2009 (2009-07-01), - 3 July 2009 (2009-07-03), pages 1-10, XP008150287, Vienna, Austria * sections 2.1, 3.1, 3.1.1, 3.1.2 *</p> <p style="text-align: center;">----- -/--</p>	1-10



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

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Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Kröner, Sabine

INTERNATIONAL SEARCH REPORT

International application No

PCT/IT2012/000225

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	IOANNIS STAMOS ET AL: "Integrating Automated Range Registration with Multiview Geometry for the Photorealistic Modeling of Large-Scale Scenes", INTERNATIONAL JOURNAL OF COMPUTER VISION, KLUWER ACADEMIC PUBLISHERS, BO, vol. 78, no. 2-3, 10 November 2007 (2007-11-10), pages 237-260, XP019581884, ISSN: 1573-1405 * sections 4, 4.1 * -----	1,9,10
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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