

(19)



(11)

EP 1 849 122 B1

(12)

EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:
14.04.2010 Bulletin 2010/15

(51) Int Cl.:
G06K 9/00 (2006.01)

(21) Application number: **06711154.2**

(86) International application number:
PCT/IL2006/000172

(22) Date of filing: **09.02.2006**

(87) International publication number:
WO 2006/087701 (24.08.2006 Gazette 2006/34)

(54) **FACIAL RECOGNITION AND THE OPEN MOUTH PROBLEM**

GESICHTSERKENNUNG UND DAS PROBLEM MIT DEM OFFENEN MUND

RECONNAISSANCE FACIALE ET PROBLEME DE LA BOUCHE OUVERTE

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IS IT LI LT LU LV MC NL PL PT RO SE SI SK TR

- **KIMMEL, Ron**
34672 Haifa (IL)

(30) Priority: **16.02.2005 US 58171**

(74) Representative: **Dennemeyer, John James et al**
Dennemeyer & Associates S.A.
Patents-trademarks-Designs
P.O. Box 1502
1015 Luxembourg (LU)

(43) Date of publication of application:
31.10.2007 Bulletin 2007/44

(73) Proprietor: **Technion Research & Development Foundation Limited**
32000 Haifa (IL)

(56) References cited:
EP-A- 1 039 417 WO-A-2004/032061
WO-A-2004/044689 US-A1- 2004 175 039

(72) Inventors:

- **BRONSTEIN, Michael**
32984 Haifa (IL)
- **BRONSTEIN, Alexander**
32984 Haifa (IL)

- **ALEXANDER M. BRONSTEIN; MICHAEL M. BRONSTEIN; RON KIMMEL: "Three-Dimensional Face Recognition"[Online] 10 December 2004 (2004-12-10), XP002385049 Retrieved from the Internet: URL: <http://www.cs.technion.ac.il/~bron/publications/BroBroKimJCV05.pdf> [retrieved on 2006-06-12]**

EP 1 849 122 B1

Note: Within nine months of the publication of the mention of the grant of the European patent in the European Patent Bulletin, any person may give notice to the European Patent Office of opposition to that patent, in accordance with the Implementing Regulations. Notice of opposition shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European Patent Convention).

DescriptionFIELD AND BACKGROUND OF THE INVENTION

5 **[0001]** The present invention relates to facial recognition and the open mouth problem and, more particularly, but not exclusively to a method and apparatus for three dimensional facial recognition that can distinguish between different expressions of the same face on the one hand and different faces on the other hand.

[0002] An important question in understanding the structure of facial appearance, is what are the invariants of a human face under various expressions. The change of a face by expressions makes modelling of the face and extraction of features that are not influenced by those changes a challenging task.

10 **[0003]** It was previously suggested to treat faces as deformable surfaces in the context of Riemannian geometry, and modelling facial expressions as near-isometric transformations of the facial surface. The method of bending-invariant canonical forms was used to construct a representation of the faces, invariant to such isometric transformations. The isometric model, however, has difficulties in handling facial expressions that change the topology of the facial surface. One such example is comparing a face with an open mouth to one with a closed mouth.

15 **[0004]** That is, how can someone's face be given a unique description, that does not change by his or her expression. Important examples include the problem of face recognition in computer vision, texture mapping for facial animation in computer graphics, emotion interpretation in psychology, and measurement of geometric parameters of the face in cosmetic surgery. The variability of the face appearance due to the non-rigid structure of the human face makes this a non-trivial task and challenges for a convenient model to analyze the nature of facial expressions. In previous work we proposed an isometric model for the face geometry, according to which expressions can be approximated by metric preserving transformations of the facial surface. The use of such a model allows us to use the bending-invariant canonical forms in order to construct an expression-invariant representation of the face. Our isometric model was shown to be applicable to strong facial expressions, but it implicitly assumes that facial expressions are *topology-preserving*. Thus we had a problem comparing faces with an open mouth to those with a closed one, which is a case in which the topology is not preserved.

20 **[0005]** Figure 1A demonstrates this phenomenon by showing the geodesics 3, 4 and 5 between two points on the upper and the lower lips of a face 2. As long as the mouth is closed, the geodesics cross the lips without any significant change, even for extreme facial expressions, compare geodesics 3 and 4. However, opening the mouth changes completely the length of the minimal geodesics. In this case, the geodesic between the two lips passes along the lip contour, as indicated by reference numeral 5. In other words, our previous model always required that in all expressions the mouth has to be either always closed or always open.

25 **[0006]** The previous model is discussed in International Patent Application Publication No. WO 2004/032061 published 15th April 2004.

30 **[0007]** International Patent Application Publication No. WO2004/044689 published 27th May 2004 teaches a method for analyzing, classifying and recognizing geometric surfaces. Geometric surfaces are treated as Riemann manifolds and the conformal structure corresponding to the surfaces is calculated.

35 **[0008]** There is thus a widely recognized need for, and it would be highly advantageous to have, a facial recognition system devoid of the above limitations, and able to recognize the face irrespective of whether the mouth is open or closed, overcoming the fact that the two cases are topologically different.

SUMMARY OF THE INVENTION

40 **[0009]** According to one aspect of the present invention there is provided a method of providing an electronic representation of a face having a mouth and being able to adopt open-mouthed or closed mouth states, for electronic face processing, the method characterized by:

identifying a mouth region within the face;

applying a topological constraint to the mouth region, and

50 representing the face with the constraint, thereby to render the representation invariant to a respective open or closed mouth state.

[0010] Preferably, the topological constraint is selected such that a geodesic contour travels about the mouth region over a substantially similar path irrespective of whether the face is in an open mouth state or a closed mouth state.

55 **[0011]** Preferably, the topological constraint comprises setting the mouth region into a permanently open state.

[0012] Preferably, setting the mouth region into a permanently open state comprises cropping about the mouth region.

[0013] Preferably, the topological constraint comprises setting the mouth region into a permanently closed state.

[0014] Preferably, the identifying a mouth region comprises identifying lips.

[0015] Preferably, the identifying lips comprises texture processing.

[0016] The method may comprise cropping the face by:

5 selecting a first geodesic contour about an invariant reference point on the face,
setting a region within the first geodesic contour as a first mask,
selecting a second geodesic about a boundary of the identified mouth region,
setting a region within the second geodesic as a second mask, and
forming a final mask from a union of the first mask and the second mask.

10 [0017] According to a second aspect of the present invention there is provided a method of cropping a representation of a face for electronic processing, the method comprising:

15 selecting a first geodesic contour about an invariant reference point on the face,
setting a region within the first geodesic contour as a first mask,
selecting a second geodesic contour about a boundary of the identified mouth region,
setting a region within the second geodesic contour as a second mask, and
forming a final mask from a union of the first mask and the second mask.

20 [0018] According to a third aspect of the present invention there is provided apparatus for providing an electronic representation of a face having a mouth and being able to adopt a mouth open state comprising at least an open-mouthed state and a closed mouth state, for electronic face processing, the apparatus comprising:

25 a mouth region identifier for identifying a mouth region within the face; and
a constraint application unit for applying a topological constraint to the mouth region,
the apparatus being configured to apply the constraint to a representation of the face, thereby to render the representation invariant to a respective mouth open state.

[0019] Preferably, the topological constraint is selected such that a geodesic contour travels about the mouth region over a substantially similar path irrespective of the mouth open state.

30 [0020] Preferably, the topological constraint comprises setting the mouth region into a permanently open state.

[0021] Preferably, setting the mouth region into a permanently open state comprises cropping about the mouth region.

[0022] Preferably, the topological constraint comprises setting the mouth region into a permanently closed state.

[0023] Preferably, the identifying a mouth region comprises identifying lips.

[0024] Preferably, the identifying lips comprises texture processing.

35 [0025] The apparatus may comprise a cropping unit for cropping the face, the cropping unit comprising:

a first mask unit for selecting a first geodesic contour about an invariant reference point on the face, and setting a region within the first geodesic contour as a first mask,
a second mask unit for selecting a second geodesic about a boundary of the identified mouth region, and setting a region within the second geodesic as a second mask, and
40 a third mask unit for forming a final mask from a union of the first mask and the second mask.

[0026] The apparatus may comprise:

45 a geodesic converter, for receiving 3-dimensional topographical data of the geometric body as a triangulated manifold, and for converting the triangulated manifold into a series of geodesic distances between pairs of points of the manifold, and

50 a multi-dimensional scaler, connected subsequently to the geodesic converter, for forming a low dimensional Euclidean representation of the series of geodesic distances, the low dimensional Euclidean representation providing a bending invariant representation of the geometric body suitable for matching with other geometric shapes, the geodesic converter and the multidimensional scaler both being located prior to the mouth region identifier.

[0027] The apparatus may comprise a subsampler located prior to the geodesic converter, configured to subsample the triangulated manifold, and to provide to the geodesic converter a subsampled triangulated manifold.

55 [0028] Preferably, the manifold comprises a plurality of vertices and wherein the subsampler is operable to select a first vertex and to iteratively select a next vertex having a largest geodesic distance from vertices already selected, until a predetermined number of vertices has been selected.

[0029] Preferably, the subsampler is operable to use the fast marching method for triangulated domains to calculate geodesic distances between vertices for the iterative selection.

[0030] Preferably, the geometric body is a face, having soft geometric regions, being regions of the face susceptible to short term geometric changes, and hard geometric regions, being regions substantially unsusceptible to the short term geometric changes, the apparatus comprising a preprocessor, located prior to the subsampler, for removing the soft geometric regions from the face.

[0031] Preferably, the preprocessor is operable to identify the soft regions by identification of an orientation point on the face.

[0032] Preferably, the orientation point is at least one of a nose tip, a pair of eyeball centers and a mouth center.

[0033] Preferably, the preprocessor is further operable to center the face.

[0034] Preferably, the preprocessor is further operable to crop the face.

[0035] Preferably, the preprocessor is operable to carry out removal of the soft regions by application of a geodesic mask.

[0036] Preferably, the geodesic converter is operable to use the fast marching method for triangulated domains to calculate the geodesic distances.

[0037] The apparatus may comprise a triangulator for forming the triangulated manifold from scan data of a geometric body.

[0038] The apparatus is preferably further operable to embed the triangulated manifold into a space of higher than two dimensions, thereby to include additional information with the topographical information.

[0039] Preferably, the additional information is any one of a group comprising texture information, albedo information, grayscale information, and color information.

[0040] Preferably, the subsampler comprises an optimizer for allowing a user to select an optimum subsampling level by defining a trade-off between calculation complexity and representation accuracy.

[0041] Preferably, the multi-dimensional scalar is configured such that the Euclidean representation comprises a predetermined number of eigenvalues extractable to be used as co-ordinates in a feature space.

[0042] Preferably, the predetermined number of eigenvalues is at least three, and the feature space has a number of dimensions corresponding to the predetermined number.

[0043] According to a fourth aspect of the present invention there is provided apparatus for cropping a representation of a face for electronic processing, the face having differential mouth opening states including an open mouth state, a closed mouth state and at least one intermediate state therebetween, the apparatus comprising:

a first masking unit for selecting a first geodesic contour about an invariant reference point on the face, and setting a region within the first geodesic contour as a first mask,

a second masking unit for selecting a second geodesic contour about a boundary of the identified mouth region, and setting a region within the second geodesic contour as a second mask, and

a third masking unit for forming a final mask from a union of the first mask and the second mask, thereby to provide cropping of the face such as to obtain a full facial region and negligible background within the cropping for any of the mouth opening states.

[0044] Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. The materials, methods, and examples provided herein are illustrative only and not intended to be limiting.

[0045] Implementation of the method and system of the present invention involves performing or completing certain selected tasks or steps manually, automatically, or a combination thereof. Moreover, according to actual instrumentation and equipment of preferred embodiments of the method and system of the present invention, several selected steps could be implemented by hardware or by software on any operating system of any firmware or a combination thereof. For example, as hardware, selected steps of the invention could be implemented as a chip or a circuit. As software, selected steps of the invention could be implemented as a plurality of software instructions being executed by a computer using any suitable operating system. In any case, selected steps of the method and system of the invention could be described as being performed by a data processor, such as a computing platform for executing a plurality of instructions.

BRIEF DESCRIPTION OF THE DRAWINGS

[0046] The invention is herein described, by way of example only, with reference to the accompanying drawings. With specific reference now to the drawings in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of the preferred embodiments of the present invention only, and are presented in order to provide what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the invention. In this regard, no attempt is made to show structural details of the invention in more detail than

is necessary for a fundamental understanding of the invention, the description taken with the drawings making apparent to those skilled in the art how the several forms of the invention may be embodied in practice.

[0047] In the drawings:

- 5 FIG. 1A is a simplified diagram showing a face in different mouth open states, illustrating a geodesic drawn between the lower and upper lips in the different mouth open states and illustrating why the geodesic model has difficulty with mouth open states;
- FIG. 1B is a simplified diagram showing the same set of mouth open states where the geodesic is constrained according to a first preferred embodiment of the present invention to pass around the mouth irrespective of the mouth being open or shut;
- 10 FIG. 1C is a simplified diagram illustrating reference points taken over a face and showing how they move as the face enters different mouth open states;
- FIGs. 1D and 1E are simplified diagrams illustrating absolute and relative changes in distances respectively due to changes in expression of the same face;
- 15 FIG. 2A is a simplified diagram of apparatus for converting 3D data into a canonical form representation of a face;
- FIG. 2B is a simplified diagram of apparatus for distance measurement between faces using representations produced by the apparatus of FIG. 2A;
- FIG. 3 is a simplified flow diagram illustrating a process for applying a constraint around the mouth region of a facial representation produced by the apparatus of FIG. 2A;
- 20 FIG. 4 is a simplified flow diagram illustrating in greater detail the geometric processing of FIG. 3;
- FIG. 5 is a simplified flow diagram illustrating in greater detail the lip cropping process of FIG. 3;
- FIG. 6 is a simplified flow diagram showing facial cropping for use with the apparatus of FIG. 3;
- FIG. 7 is a simplified flow diagram illustrating a variation of facial cropping to ensure that maximum facial area and minimum non-facial area remains after cropping irrespective of a mouth open state of the face;
- 25 FIG. 8 is a simplified diagram illustrating a facial manifold and showing the identification of an absolute reference point;
- FIG. 9 shows the development of relative reference points over the manifold following identification of the absolute reference point;
- FIG. 10 is a series of the same face. The first three faces in the series illustrate the development of a boundary geodesic for face cropping, and the remaining four faces illustrate lip cropping for different mouth open states of the face;
- 30 FIG. 11 illustrates different expression types with which the system of the present embodiments was tested;
- FIG. 12 illustrates different faces used to build up the database with which the present embodiments were tested;
- FIG. 13 illustrates the different expressions used with the faces of FIG. 12 in the database,
- FIG. 14 illustrates three degrees of open mouth used with the expressions of FIG. 13;
- 35 FIG. 15A illustrates results obtained using the present embodiments, in which faces cluster irrespective of the expressions; and
- FIG. 15b illustrates results obtained using surface matching, in which the faces fail to cluster.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

40 **[0048]** The present embodiments comprise a solution to the open mouth problem that operates by enforcing a constraint to the topology on the facial surface, in particular about the mouth region. In one embodiment the constraint is that the mouth is always closed, in effect gluing the lips. In an alternative embodiment the constraint is that the mouth is always open, and this is achieved by disconnecting the lips. The disconnection can be achieved by introducing a cut in the surface when the mouth is closed. In either case the constraint provides for a geodesic that passes vertically through the lip region to follow the same path regardless of whether the mouth is open or closed.

45 **[0049]** The examples herein focus on the second, disconnecting, solution, but the skilled person will appreciate that the principles described herein are readily applicable to the first, glued, solution as well. The following description presents the concept of *topologically-constrained canonical forms*, that allow us to construct a representation of the face that is insensitive to facial expressions, and remains so irrespective of changes of state between closed and open mouths.

50 **[0050]** The principles and operation of a facial recognition system according to the present invention may be better understood with reference to the drawings and accompanying description.

55 **[0051]** Reference is now made to Fig. 1B, which shows the same series of faces as in FIG. 1A, which vary in the extent to which the mouths are open. According to the present embodiment the region of the mouth is excluded from consideration when drawing geodesics, so that the representation always treats the mouth as open, and the geodesic goes around the excluded region. Therefore it makes no difference whether the mouth is open or shut. The geodesic *always* goes around the mouth, and the mouth open state now ceases to have topological relevance for the model.

[0052] Reference is now made to Fig. 1C, which is a simplified diagram illustrating how the above operation may be

performed. A face 8 is converted into a cloud of sample points. The sample points avoid the mouth area, since the mouth area is excluded. Furthermore all geodesics avoid the mouth area so that even when the sample points move, the relationships between the sample points, as measured by the linking geodesics does not change very much. Thus the geometric relationship between the sample points does not change significantly whatever the expressions of the face. Figs 1D and 1E show absolute and relative changes respectively in distances for changes in expression of the same face. The distance measurement used is discussed in more detail hereinbelow.

[0053] The issue is now considered in greater detail. Reference is now made to Fig. 2A, which is a simplified diagram showing apparatus for obtaining 3-Dimensional data of a geometric body for classification, including matching, according to a first preferred embodiment of the present invention. The preferred embodiments relate specifically to matching of faces but the skilled person will be aware that the principles of the present invention are applicable to any geometric body having a three-dimensional structure.

[0054] Apparatus 10 comprises a three dimensional scanner 12 for obtaining three-dimensional topographical data of the body. Several types of scanner are described hereinbelow together with brief discussions of how to process data therefrom in some of the cases.

[0055] Data from the three-dimensional scanner 12 is passed to a triangulator 14. The triangulator may perform triangulation on the data received from the scanner in order to generate a three-dimensional triangulated manifold to represent the topological features of the body. The exact operation of the triangulator to derive the manifold may vary depending on the way in which the 3D information is gathered. In certain cases the manifold may be formed directly from the gathered data without the need for any intervening processing stage. The manifold preferably represents all of the three-dimensional topology of the body and therefore is in theory sufficient for allowing matching. However, in practice, direct comparisons using the triangulated manifold have a number of disadvantages, as will be demonstrated in the results given hereinbelow. They requires a large amount of calculation. Matching does not distinguish reliably between different faces. Moreover matching generally fails when the same face has a different expression and matching is unreliable even when the same face is posed at a different angle.

[0056] Embodiments of the present invention therefore preferably include four additional processing stages, the first of which is a preprocessor 16. Preprocessor 16 takes a reference point in order to determine an orientation around the manifold. A reference point which is relatively easy to find automatically from a manifold of a face is the tip of the nose. Other possible reference points include centers of eyeballs and the center of the mouth. Once the preprocessor has found the tip of the nose (Fig. 8) it is able to orientate itself with respect to the rest of the face and then parts of the face whose geometry is particularly susceptible to expressions, hereinafter referred to as soft regions, can be ignored. Parts of the face that are invariant with change of expression and the like, hereinafter hard regions, can be retained or even emphasized. Further relative reference points can be added, as shown in Fig. 9 below. As will be explained in greater detail below, the definition of soft regions is not fixed. For some methods and in some circumstances soft regions to be excluded may include all of the lower region of the face around the mouth. It is to be noted that the exclusion referred to here is the exclusion of regions from adding reference points, and is not the same as lip cropping discussed hereinbelow. In other cases less drastic exclusions may be considered. In one embodiment, soft regions are removed using a geodesic mask. The mask may be applied separately to a texture map of the face and a depth map of the face.

[0057] Following the preprocessor is a subsampler 18. The subsampler 18 takes the preprocessed manifold and removes points so as to produce a less well defined manifold, but one which still defines the essential geometry of the face it is desired to match. In preferred embodiments, the user is able to select the number of points to trade off between accurate matching - a large number of points - and faster processing — a smaller number of points. As will be discussed in greater detail below, a preferred embodiment of the sub-sampler uses the Voronoi subsampling technique which begins at an initial point or vertex on the manifold and then adds the point or vertex having the greatest distance therefrom. The procedure is repeated iteratively until the selected number of points are included. Preferably the technique uses geodesic distances; which may be obtained using the fast marching method for the triangulated domain (FMM-TD), as described below.

[0058] Following the subsampler is a geodesic converter 20. The geodesic converter 20 receives the list of points of the subsampled manifold and calculates a vector for each pair of points. The vectors are expressed as geodesic distances, and the fast marching algorithm for the triangulated domain is again used to obtain the geodesic distances in as efficient a manner as possible.

[0059] Following the geodesic converter is a multi-dimensional scaler 22, which takes the matrix of the geodesic distances calculated by the geodesic converter 20, referred to below as the distance matrix, and forms a low dimensional Euclidean representation of the series of geodesic distances, using multi-dimensional scaling. Multi-dimensional scaling is discussed in detail below. The low dimensional Euclidean representation provides a bending invariant representation of the geometric body, as will be explained in the discussion on multi-dimensional scaling below. The use of such a bending invariant representation ensures that the matching process is not fooled by, for example, scans of the head at different angles.

[0060] The output 24 of the multi-dimensional scalar is a representation of the 3D face in terms of Euclidean distances

between surface points, referred to hereinbelow as the canonical form representation.

[0061] Reference is now made to Fig. 2B, which is a simplified diagram showing a matching apparatus for matching two faces using the canonical form output as described above. The matcher 30 may be a continuation of the apparatus 10 or may be supplied as a separate unit. The matcher 30 comprises a distance calculator 32, which takes as input two canonical form representations 34 and 36, and calculates a distance therebetween. The distance calculation may use any suitable method for comparison of the canonical forms for each of the faces to be matched. A straightforward approach is to measure a distance between two sets of points, using, for example, the Hausdorff metric. However, the Hausdorff metric based method is computationally extensive.

[0062] An alternative approach, used in the present embodiments, takes the first m eigenvalues obtained from the MDS procedure to provide coordinates in a low-dimensional feature space. Although the dominant eigenvalues do not describe the canonical form entirely, it is reasonable that similar faces have similar eigenvalues (and thus form clusters in the feature space). A distance is calculated between the geometric bodies, or, as will be described below, plotted on a graph of the feature space and a thresholder 38, which is connected subsequently to the distance calculator, thresholds the calculated distance to determine the presence or absence of a cluster in the feature space, the cluster indicating a match. In the embodiments described in detail herein, the first three Eigenvalues are taken and are plotted in a three dimensional feature space.

[0063] A quantitative validation of our topologically-constrained isometric model is possible by tracking a set of feature points on the facial surface and measuring how the distances between them change due to facial expressions, while ensuring that the topology of the surface is preserved. Unfortunately, there are very few points that can be located accurately on a human face. In order to overcome this difficulty, we placed 133 white round markers (approximately 2 mm in diameter) as invariant fiducial points, onto our subject's face. These markers are explained with respect to Fig. 1C, which shows a facial expressions experiment. On the leftmost side of the figure is a first facial image 8 with the markers. Then, moving towards the right are examples of four facial expressions with the same marked reference points, but the reference points have moved due to the changing expressions of the subject. The markers are selected so as to be easily detected under a variety of facial expressions as exemplified by the four faces towards the left in the figure. In the experiment, sixteen faces were in fact used, between them having weak, medium and strong facial expressions, including open and shut mouth. Lips were cut out, in the manner discussed with respect to Fig. 1B above, to enforce a fixed topology. The reference points were manually labelled; then the Fast Marching algorithm was used to compute the geodesic distances between them. For details of the Fast Marching algorithm see R. Kimmel and J. A. Sethian. Computing geodesic on manifolds. In Proc. US National Academy of Science, volume 95, pages 8431-8435, 1998.

[0064] As explained, due to the constraint that all geodesics must run around the mouth irrespective of whether the mouth is actually open or not, the distances did not change that much for different mouth open states.

[0065] In order to quantify the changes of the distances due to expressions, we use two measures: the absolute error w.r.t the reference distances (the reference distances were averaged on the neutral expressions):

$$\epsilon_i^{abs} = d_i - d_i^{ref}, \text{ and the relative error } \epsilon_i^{rel} = (d_i - d_i^{ref}) / d_i^{ref} \text{ (here } d_i \text{ denotes the } i\text{-th distance}$$

and d_i^{ref} is the corresponding reference distance). The distributions of ϵ^{abs} and ϵ^{rel} are shown in Figures 1D and 1E respectively. The standard deviation of ϵ^{abs} is 5:89 mm for geodesic distances and 12:03 mm for Euclidean ones (a difference of 104:3%). The standard deviation of ϵ^{rel} was 15: 85% for geodesic distances and 39: 6% for Euclidean ones (a difference of 150:2%).

[0066] The conclusion of this experiment is two-fold. First, the changes of the geodesic distances due to facial expressions are insignificant for exaggerated expressions, which justifies the present model. Secondly, Euclidean distances are much more sensitive to changes due to facial expressions compared to the geodesic ones. This observation will be reinforced by the results presented hereinbelow, where we compare our method to a method that treats facial surfaces as rigid objects.

Preprocessing

[0067] The geometry of the face is acquired by a range camera and has to be processed before the canonical form is computed. The raw range data is given as a cloud of points, that can be triangulated or represented as a parametric manifold as shown in Fig. 1C. Preprocessing according to the present embodiments is illustrated in the flow chart of Fig. 3. As illustrated the process includes three steps:

- (i) geometric processing of the facial surface S3.1;
- (ii) lip cropping S3.2; and
- (iii) cropping the whole face S3.3.

[0068] Geometric processing S3.1 is shown in greater detail in the flow chart of Fig. 4 to include three stages of spike removal S4.1, hole filling S4.2 and selective smoothing, S4.3. For details on the three stages of geometric processing see M. Bronstein, A. Bronstein, and R. Kimmel. Three-dimensional face recognition. Technical Report CIS-2004-04, Dept. of Computer Science, Technion, Israel, 2003.

[0069] Lip cropping is shown in greater detail in the simplified flow chart of Fig. 5. Lip cropping is preferably performed by first segmenting the lips based on the texture information S5.1, and then removing the corresponding points in the 3D data S5.2.

[0070] The whole face cropping procedure is performed using a modification of the *geodesic mask* proposed in our US Patent Application No. 10/284,281. The unmodified version is shown in Fig. 6. The key idea of the geodesic mask computation is locating an invariant "source" point on the face (e.g. the tip of the nose), S6.1, and measuring an equidistant (in sense of the geodesic distances) contour around it, S6.2. The geodesic mask is defined in S6.3 as the interior of this contour and all points outside the contour are removed. This allows us to crop the facial surface in a consistent manner, insensitively to facial expressions. In case of topological changes, however, the geodesic mask loses its invariance, as the geodesic distances are influenced by the "hole" created at the mouth location. That is to say, if the user opens his mouth, the chin rotates downwardly away from the front of the face, and the boundary geodesic tends therefore to lose the bottom of the chin.

[0071] Reference is now made to Fig. 7, which is a simplified flow chart of a method of carrying out whole face cropping which overcomes the above problem. As shown in Fig. 7 the embodiment uses two masks. A first mask is computed in stages S7.1 to S7.4. in which an equidistant region around the nose tip is computed on the facial surface as before and ignoring the fact that the lips are cut.

[0072] A second mask is then defined in stages S7.5 to S7.7, in which an equidistant region around the lips is used. In S7.5 we use all the points along the lip perimeter as source points. In S7.6 an equidistant geodesic contour is set around the lips and in S7.7 the region within the contour is set as a second mask. In stage 7.8 a union of the first and second masks is calculated and the final geodesic mask is set in stage 7.9 as that union. Typically the cropped surface contains $N \approx 3000$ points.

[0073] Figure 8 is a simplified illustration of a manifold and shows the selection of an invariant point, the nose tip 60, which is an easy point for a machine to find and use as a reference. As will be shown below, the system can be given improved reliability by using two such points, for example the nose tip and the center of the bridge of the nose.

[0074] Fig. 9 shows a facial manifold with a cloud of points developed from an initial reference point such as that shown in Fig. 8.

[0075] Figure 10 is a worked example, on a manifold, of the geodesic mask computation of Figs 3-7 and its insensitivity to facial expressions. As shown in face 10a, computation of the geodesic mask requires setting up of equidistant contours from first fixed sources, in this case equidistant contours are measured from two sources, one located at the tip of the nose and the second being the center of the bridge of the nose (left). In face 10b, equidistant contours are measured from sources located on the perimeter of the lips. In face 10c the final mask is obtained as a union of the two regions. In the second row: faces 10d to 10g show the final masks computed in the same way but with different initial expressions or degrees of open mouth. The examples show that the final mask is an effective capture of the outline of the face whatever the extent of the mouth being open. That is to say the geodesic mask is shown to have good insensitivity to facial expressions.

4 Topologically-constrained canonical forms

[0076] Isometric transformations preserve intrinsic or geodesic distances among all points. Our model of the face thus assumes that the geodesic distance d_{ij} between any given two points x_i, x_j on the facial surface remains unchanged.

The first problem is that a discrete set of points $\{x_i\}_{i=1}^N$ can be ordered arbitrarily, and thus the matrix $D = (d_{ij})$ is invariant up to some permutation of the rows and columns. Moreover, when sampling a surface, there is no guarantee that the surface will be sampled at similar points, nor even that the number of points in two surfaces is necessarily the same. This makes the computation of such an invariant impractical.

[0077] An alternative is to avoid dealing explicitly with the matrix of geodesic distances, and replace the curved surface with its Riemannian metric by a different dual surface. Intrinsic geodesic distances are replaced by Euclidean ones in the embedding space. The new surface, approximates the original one in some optimal way. Such a procedure is called

flat embedding, and the resulting set of points x'_i in the Euclidean space is called the *bending invariant canonical form* of the face. Unlike the matrix D , the canonical form (though inevitably being an *approximate* representation of the original surface) is invariant, up to rotation, translation and reflection, which is much easier to deal with when trying to match two non-rigid surfaces.

[0078] We would like to find the "most isometric" embedding, the one that deforms the manifold distances the least.

In practice, we have a finite discrete set of N manifold samples $\{\mathbf{x}_i\}_{i=1}^N$ (represented as a $3 \times N$ matrix $X = (x_1; \dots; x_N)$) and a set of N^2 mutual geodesic distances between these samples. We consider a mapping of the form

$\varphi : (\mathcal{M}, d) \rightarrow (\mathbb{R}^m, d')$, which maps the manifold samples x_i into points x'_i in an m -dimensional Euclidean

space, such that the geodesic distances d_{ij} are replaced by Euclidean ones $d'_{ij} = \|\mathbf{x}'_i - \mathbf{x}'_j\|_2$.

[0079] The embedding error can be measured as a discrepancy between the geodesic and the resulting Euclidean distances using some norm,

$$s(\mathbf{X}'; \mathbf{D}) = \|\mathbf{D} - \mathbf{D}'(\mathbf{X}')\|, \quad (1)$$

where $\mathbf{X}' = (x'_1; \dots; x'_N)$ is an $m \times N$ matrix representing the points in the embedding space, and \mathbf{D}' is the matrix of mutual Euclidean distances depending on the points configuration \mathbf{X}' . The function (1) is referred to hereinbelow as *stress*.

[0080] Finding the best approximate flat embedding is possible by minimization of $s(\mathbf{X}'; \mathbf{D})$ with respect to \mathbf{X}' . A family of algorithms used to carry out such an approximate flat embedding is usually referred to as *multidimensional scaling* (MDS). These algorithms differ in the choice of the embedding error criterion and the numerical method used for its minimization.

[0081] One straightforward possibility is to choose the norm in (1) to be Euclidean, and thus have the metric distortion defined as a sum of squared differences

$$s(\mathbf{X}'; \mathbf{D}) = \sum_{i>j} (d_{ij} - d'_{ij})^2, \quad (2)$$

and the MDS is posed as a least-squares (LS) problem and is known as LS-MDS. We used the iterative SMACOF algorithm to compute the canonical forms. The SMACOF algorithm is disclosed in I. Borg and P. Groenen. Modern multidimensional scaling - theory and applications, Springer-Verlag, Berlin Heidelberg New York, 1997; and also in J. De-Leeuw. Recent developments in statistics, chapter Applications of convex analysis to multidimensional scaling, pages 133-145. North-Holland, Amsterdam, 1977.

[0082] When the embedding is performed into a space with $m = 3$ dimensions, the canonical form can be plotted as a surface. Figure 11 depicts canonical forms of one subject with different facial expressions. More particularly Fig. 11, faces 11a-11m shows examples of topologically-constrained canonical forms of faces with strong facial expressions, including expressions with closed, open, and partially open mouth. For comparison, faces 11k and 11m are a canonical form of a different subject.

[0083] It demonstrates that although the facial surface changes are substantial, the changes between the corresponding canonical forms are insignificant.

[0084] Additional objects, advantages, and novel features of the present invention will become apparent to one ordinarily skilled in the art upon examination of the following examples, which are not intended to be limiting. Additionally, each of the various embodiments and aspects of the present invention as delineated hereinabove and as claimed in the claims section below finds experimental support in the following examples.

[0085] The above-described approach was tested on a data set containing 102 instances of 6 subjects and one mannequin (Eve). The set of faces is shown in Fig. 12, in which all the faces have neutral expressions. As illustrated in Fig. 13 with just a single face, the human subjects appear in the data base with different facial expressions, classified into 7 groups (neutral expression + 6 expressions with open or shut mouth). Furthermore as shown in Fig. 14 the expressions each appear in three strengths, weak, medium, and strong. A neutral expression is the natural posture of the face with a closed mouth; strong expressions are extreme postures that obviously rarely occur in real life. Head rotations of up to about 10 degrees were allowed.

[0086] Using the database, an experiment was carried out to test the sensitivity of the topologically constrained canonical forms to extreme facial expressions including open and closed mouth.

[0087] As a reference, the facial surfaces were also compared as rigid objects. Surface matching (both the facial

surfaces and the canonical forms) was carried out by comparing their moments.

[0088] The surface is described as a vector of its 56 high-order moments, and the Euclidean norm is used to measure the distance between these vectors.

[0089] Figs. 15A and 15B are graphical representations of the results of the experiment (15A) and the control (15B). More particularly Figs. 15A and 15B depict a low-dimensional representation (obtained by MDS) of the dissimilarities (distances) between faces. Each symbol on the plot represents a face; colors denote different subjects; the symbol's shape represents the facial expression and its size represents the expression strength. Ideally, clusters corresponding to each subject should be as close as possible (meaning that the representation is insensitive to facial expressions) and as distant as possible from other subjects, which means that the representation allows us to discriminate between different subjects, and not between different expression. That is, the within class distances should be as small as possible, while the between classes distances should be as large as possible. It can be seen that using straightforward rigid surface matching as in the control in Fig. 15B, the clusters overlap, implying that variability due to facial expressions is larger than due to the subject's identity. On the other hand, using topologically-constrained canonical forms as in Fig. 15A, we obtain tight and distinguishable clusters.

[0090] Table 1 below is a description of the facial expressions in the data set used in the experiment of Fig. 15 and the inter-cluster to intra-cluster dissimilarity ratio using original and canonical surface matching. The triple asterisk in the table denotes an artificial subject.

Subject	Color	Neut	Weak	Med	Str	Shut	Open	ζ_k^{can}	ζ_k^{orig}
Michael	Red	2	2	10	6	6	14	2.55	17.10
Eyal	green	1	2	8	5	2	14	1.35	8.61
Guy	magenta	3	4	6	4	5	12	1.44	10.64
Mitya	Yellow	2	9	7	5	6	17	2.40	14.77
Boaz d.	Cyan	3	3	3	1	6	4	1.30	3.01
David d.	Magenta	1	2	4	3	1	9	0.97	8.65
Eve***	Black	6	-	-	-	6	-	0.11	0.70

[0091] Table 1, final two columns, shows for the canonical forms case and the control respectively, the values of the ratio of the maximum inter-cluster to minimum intracluster dissimilarity

$$\zeta_k = \frac{\max_{i,j \in C_k} \eta_{ij}}{\min_{i \notin C_k, j \in C_k} \eta_{ij}}, \quad (3)$$

in which C_k denotes indexes of the k -th subject's faces,

$C = \cup_k C_k$ and η_{ij} denotes dissimilarities between faces i and j) for facial and canonical surface matching. This criterion is convenient being scale-invariant; it measures the tightness of each cluster of faces that belong to the same subject and its distance from other clusters. Ideally, ζ_k should tend to zero. The approach of the present embodiments, 9th column, outperforms rigid facial surface matching, the 10th column, by up to 790: 3% in the sense of ζ_k .

Conclusions

[0092] In our previous patent application referred to hereinabove we used canonical forms to solve the problem of 3D face recognition.

[0093] In the present application we carry out a generalization of that approach to handle facial expressions with an open mouth. The method of topologically-constrained canonical forms is applicable to facial expressions with both closed and open mouth, and can thus handle extreme facial expressions. The resulting representation is especially suitable for 3D face recognition in a natural environment, for example, when a subject is speaking.

[0094] It is expected that during the life of this patent many relevant 3D data gathering and topology measurement devices and systems as well as devices, systems and methods for measuring contours and carrying out comparisons based on representations of three-dimensional data will be developed and the scope of the corresponding terms herein

are intended to include all such new technologies *a priori*.

[0095] It is appreciated that certain features of the invention, which are, for clarity, described in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features of the invention, which are, for brevity, described in the context of a single embodiment, may also be provided separately or in any suitable subcombination.

Claims

- 10 1. A method of providing an electronic representation of a face having a mouth and being able to adopt open-mouthed or closed mouth states, for electronic face processing, the method **characterized by** :
- 15 identifying a mouth region within said face;
applying a topological constraint to said mouth region, and
representing said face with said constraint, thereby to render said representation invariant to a respective open or closed mouth state.
- 20 2. The method of claim 1, wherein said topological constraint is selected such that a geodesic contour travels about said mouth region over a substantially similar path irrespective of whether said face is in an open mouth state or a closed mouth state.
3. The method of claim 2, wherein said topological constraint comprises setting said mouth region into a permanently open state.
- 25 4. The method of claim 3, wherein setting said mouth region into a permanently open state comprises cropping about said mouth region.
5. The method of claim 2, wherein said topological constraint comprises setting said mouth region into a permanently closed state.
- 30 6. The method of claim 1, wherein said identifying a mouth region comprises identifying lips.
7. The method of claim 6, wherein said identifying lips comprises texture processing.
- 35 8. The method of claim 1, comprising cropping said face by:
- selecting a first geodesic contour about an invariant reference point on said face,
setting a region within said first geodesic contour as a first mask,
selecting a second geodesic about a boundary of said identified mouth region,
40 setting a region within said second geodesic as a second mask, and
forming a final mask from a union of said first mask and said second mask.
- 45 9. Apparatus for providing an electronic representation of a face having a mouth and being able to adopt a mouth open state comprising at least an open-mouthed state and a closed mouth state, for electronic face processing, the apparatus **characterized by**:
- 50 a mouth region identifier for identifying a mouth region within said face (Fig. 5); and
a constraint application unit for applying a topological constraint to said mouth region (Fig. 6),
the apparatus being configured to apply said constraint to a representation of said face, thereby to render said representation invariant to a respective mouth open state.
10. The apparatus of claim 9, wherein said topological constraint is selected such that a geodesic contour travels about said mouth region over a substantially similar path irrespective of said mouth open state.
- 55 11. The apparatus of claim 10, wherein said topological constraint comprises setting said mouth region into a permanently open state.
12. The apparatus of claim 11, wherein setting said mouth region into a permanently open state comprises cropping

about said mouth region.

13. The apparatus of claim 10, wherein said topological constraint comprises setting said mouth region into a permanently closed state.

14. The apparatus of claim 9, wherein said identifying a mouth region comprises identifying lips.

15. The apparatus of claim 14, wherein said identifying lips comprises texture processing.

16. The apparatus of claim 9, further comprising a cropping unit for cropping said face, said cropping unit comprising:

a first mask unit for selecting a first geodesic contour about an invariant reference point on said face, and setting a region within said first geodesic contour as a first mask,

a second mask unit for selecting a second geodesic about a boundary of said identified mouth region, and setting a region within said second geodesic as a second mask, and

a third mask unit for forming a final mask from a union of said first mask and said second mask.

17. Apparatus according to claim 9, comprising:

a geodesic converter (20), for receiving 3-dimensional topographical data of said geometric body as a triangulated manifold, and for converting said triangulated manifold into a series of geodesic distances between pairs of points of said manifold, and

a multi-dimensional scaler (22), connected subsequently to said geodesic converter, for forming a low dimensional Euclidean representation of said series of geodesic distances, said low dimensional Euclidean representation providing a bending invariant representation of said geometric body suitable for matching with other geometric shapes, said geodesic converter and said multidimensional scaler both being located prior to said mouth region identifier.

18. Apparatus according to claim 17, further comprising a subsampler (18) located prior to said geodesic converter, configured to subsample said triangulated manifold, and to provide to said geodesic converter a subsampled triangulated manifold.

19. Apparatus according to claim 18, wherein said manifold comprises a plurality of vertices and wherein said subsampler is operable to select a first vertex and to iteratively select a next vertex having a largest geodesic distance from vertices already selected, until a predetermined number of vertices has been selected.

20. Apparatus according to claim 19, wherein said subsampler is operable to use the fast marching method for triangulated domains to calculate geodesic distances between vertices for said iterative selection.

21. Apparatus according to claim 18, wherein said geometric body is a face, having soft geometric regions, being regions of said face susceptible to short term geometric changes, and hard geometric regions, being regions substantially unsusceptible to said short term geometric changes, said apparatus comprising a preprocessor (16), located prior to said subsampler, for removing said soft geometric regions from said face.

22. Apparatus according to claim 21, wherein said preprocessor is operable to identify said soft regions by identification of an orientation point on said face.

23. Apparatus according to claim 22, wherein said orientation point is at least one of a nose tip, a pair of eyeball centers and a mouth center.

24. Apparatus according to claim 21, wherein said preprocessor is further operable to center said face.

25. Apparatus according to claim 21, wherein said preprocessor is further operable to crop said face.

26. Apparatus according to claim 21, wherein said preprocessor is operable to carry out removal of said soft regions by application of a geodesic mask.

27. Apparatus according to claim 17, wherein said geodesic converter is operable to use the fast marching method for

triangulated domains to calculate said geodesic distances.

28. Apparatus according to claim 17, further comprising a triangulator (14) for forming said triangulated manifold from scan data of a geometric body.

29. Apparatus according to claim 28, further operable to embed said triangulated manifold into a space of higher than two dimensions, thereby to include additional information with said topographical information.

30. Apparatus according to claim 29, wherein said additional information is any one of a group comprising texture information, albedo information, grayscale information, and color information.

31. Apparatus according to claim 17, wherein said subsampler (18) comprises an optimizer for allowing a user to select an optimum subsampling level by defining a trade-off between calculation complexity and representation accuracy.

32. Apparatus according to claim 17, wherein said multi-dimensional scalar is configured such that said Euclidean representation comprises a predetermined number of eigenvalues extractable to be used as co-ordinates in a feature space.

33. Apparatus according to claim 32, wherein said predetermined number of eigenvalues is at least three, and said feature space has a number of dimensions corresponding to said predetermined number.

34. The apparatus of claim 9, further for cropping a representation of said face for electronic processing, said face further having at least one intermediate mouth open state between said open and said closed states, the apparatus comprising:

a first masking unit for selecting a first geodesic contour about an invariant reference point on said face, and setting a region within said first geodesic contour as a first mask,

a second masking unit for selecting a second geodesic contour about a boundary of said identified mouth region, and setting a region within said second geodesic contour as a second mask, and

a third masking unit for forming a final mask from a union of said first mask and said second mask, thereby to provide cropping of said face such as to obtain a full facial region and negligible background within said cropping for any of said mouth opening states.

Patentansprüche

1. Verfahren zur Bereitstellung einer elektronischen Darstellung eines Gesichts, das einen Mund aufweist und imstande ist, offenmundige oder geschlossene Mundzustände anzunehmen, zur elektronischen Gesichtsverarbeitung, wobei das Verfahren **gekennzeichnet ist durch**:

Identifizieren einer Mundregion in dem Gesicht;

Anwenden einer topologischen Beschränkung auf diese Mundregion und

Darstellen des Gesichts mit der Beschränkung, um **dadurch** die Darstellung gegenüber einem jeweiligen offenen oder geschlossenen Mundzustand invariant zu machen.

2. Verfahren nach Anspruch 1, wobei die topologische Beschränkung derart ausgewählt wird, dass eine geodätische Kontur ungeachtet dessen, ob das Gesicht in einem offenen Mundzustand oder einem geschlossenen Mundzustand ist, über einen im Wesentlichen ähnlichen Pfad um die Mundregion herum verläuft.

3. Verfahren nach Anspruch 2, wobei die topologische Beschränkung ein Versetzen der Mundregion in einen ständig offenen Zustand umfasst.

4. Verfahren nach Anspruch 3, wobei das Versetzen der Mundregion in einen ständig offenen Zustand ein Ausschneiden um die Mundregion herum umfasst.

5. Verfahren nach Anspruch 2, wobei die topologische Beschränkung ein Versetzen der Mundregion in einen ständig geschlossenen Zustand umfasst.

6. Verfahren nach Anspruch 1, wobei das Identifizieren einer Mundregion ein Identifizieren von Lippen umfasst.
7. Verfahren nach Anspruch 6, wobei das Identifizieren von Lippen Texturverarbeitung umfasst.

- 5 8. Verfahren nach Anspruch 1, umfassend ein Ausschneiden des Gesichts durch:

Auswählen einer ersten geodätischen Kontur um einen invarianten Bezugspunkt auf dem Gesicht,
 Festlegen einer Region innerhalb der ersten geodätischen Kontur als eine erste Maske,
 10 Auswählen einer zweiten geodätischen Kontur um eine Grenze der identifizierten Mundregion herum,
 Festlegen einer Region innerhalb der zweiten geodätischen Kontur als eine zweite Maske, und
 Bilden einer Endmaske aus einer Vereinigung der ersten Maske und der zweiten Maske.

9. Vorrichtung zum Bereitstellen einer elektronischen Darstellung eines Gesichts, das einen Mund aufweist und im-
 stande ist, einen Mundöffnungszustand anzunehmen, der wenigstens einen offenmundigen Zustand und einen
 15 geschlossenen Mundzustand umfasst, zur elektronischen Gesichtsverarbeitung, wobei die Vorrichtung **gekenn-
 zeichnet ist durch:**

einen Mundregionen-Identifizierer zum Identifizieren einer Mundregion im Gesicht (Fig. 5); und
 eine Beschränkungsanwendungseinheit zum Anwenden einer topologischen Beschränkung auf die Mundregion
 20 (Fig. 6),
 wobei die Vorrichtung so konfiguriert ist, dass sie die Beschränkung auf eine Darstellung des Gesichts anwendet,
 um **dadurch** die Darstellung gegenüber einem jeweiligen Mundöffnungszustand invariant zu machen.

10. Vorrichtung nach Anspruch 9, wobei die geodätische Beschränkung derart ausgewählt wird, dass eine geodätische
 25 Kontur ungeachtet des Mundöffnungszustands über einen im Wesentlichen ähnlichen Pfad um die Mundregion
 herum verläuft.

11. Vorrichtung nach Anspruch 10, wobei die topologische Beschränkung ein Versetzen der Mundregion in einen ständig
 30 offenen Zustand umfasst.

12. Vorrichtung nach Anspruch 11, wobei das Versetzen der Mundregion in einen ständig offenen Zustand ein Aus-
 schneiden um die Mundregion herum umfasst.

13. Vorrichtung nach Anspruch 10, wobei die topologische Beschränkung ein Versetzen der Mundregion in einen ständig
 35 geschlossenen Zustand umfasst.

14. Vorrichtung nach Anspruch 9, wobei das Identifizieren einer Mundregion ein Identifizieren von Lippen umfasst.

15. Vorrichtung nach Anspruch 14, wobei das Identifizieren von Lippen Texturverarbeitung umfasst.

- 40 16. Vorrichtung nach Anspruch 9, umfassend ein Ausschneideeinheit zum Ausschneiden des Gesichts, wobei die
 Ausschneideeinheit umfasst:

eine erste Maskeneinheit zum Auswählen einer ersten geodätischen Kontur um einen invarianten Bezugspunkt
 45 auf dem Gesicht und Festlegen einer Region innerhalb der ersten geodätischen Kontur als eine erste Maske,
 eine zweite Maskeneinheit zum Auswählen einer zweiten Geodätik um eine Grenze der identifizierten Mundre-
 gion herum und Festlegen einer Region innerhalb der zweiten Geodätik als eine zweite Maske, und
 eine dritte Maskeneinheit zum Bilden einer Endmaske aus einer Vereinigung der ersten Maske und der zweiten
 Maske.

- 50 17. Vorrichtung nach Anspruch 9, umfassend:

einen geodätischen Konverter (20) zum Empfangen von dreidimensionalen topografischen Daten des geome-
 55 trischen Körpers als eine triangulierte Mannigfaltigkeit und zum Konvertieren der triangulierten Mannigfaltigkeit
 in eine Reihe von geodätischen Entfernungen zwischen Paaren von Punkten der Mannigfaltigkeit, und
 einen multidimensionalen Skalierer (22), der dem geodätischen Konverter nachgeschaltet ist, zum Bilden einer
 niedrigdimensionalen euklidischen Darstellung der Reihe von geodätischen Entfernungen, wobei die niedrig-
 dimensionale euklidische Darstellung eine invariante Krümmungsdarstellung des geometrischen Körpers be-

reitstellt, die zur Anpassung an andere geometrische Formen geeignet ist, wobei der geodätische Konverter und der multidimensionale Skalierer beide vor dem Mundregionen-Identifizierer angeordnet sind.

- 5
18. Vorrichtung nach Anspruch 17, ferner umfassend einen Unterabtaster (18), der vor dem geodätischen Konverter angeordnet und so konfiguriert ist, dass er die triangulierte Mannigfaltigkeit unterabtastet und eine unterabgetastete triangulierte Mannigfaltigkeit an den geodätischen Konverter liefert.
- 10
19. Vorrichtung nach Anspruch 18, wobei die Mannigfaltigkeit eine Mehrzahl von Ecken umfasst, und der Unterabtaster so betrieben werden kann, dass er eine erste Ecke auswählt und iterativ eine nächste Ecke mit der größten geodätischen Entfernung von bereits ausgewählten Ecken auswählt, bis eine vorgegebene Anzahl von Ecken ausgewählt wurde.
- 15
20. Vorrichtung nach Anspruch 19, wobei der Unterabtaster so betrieben werden kann, dass er das Fast-Marching-Verfahren für triangulierte Bereiche verwendet, um geodätische Entfernungen zwischen Ecken für die iterative Auswahl zu berechnen.
- 20
21. Vorrichtung nach Anspruch 18, wobei es sich bei dem geometrischen Körper um ein Gesicht mit weichen geometrischen Regionen, die Regionen des Gesichts sind, die für kurzfristige geometrische Änderungen empfänglich sind, und harten geometrischen Regionen handelt, die Regionen sind, die im Wesentlichen unempfindlich für kurzfristige geometrische Änderungen sind, wobei die Vorrichtung einen Vorprozessor (16), der vor dem Unterabtaster angeordnet ist, zum Entfernen der weichen geometrischen Regionen aus dem Gesicht umfasst.
- 25
22. Vorrichtung nach Anspruch 21, wobei der Vorprozessor so betrieben werden kann, dass er die weichen Regionen durch Identifizierung eines Orientierungspunkts auf dem Gesicht identifiziert.
- 30
23. Vorrichtung nach Anspruch 22, wobei der Orientierungspunkt wenigstens eines von einer Nasenspitze, einem Paar von Augapfelmitten und einer Mundmitte ist.
- 30
24. Vorrichtung nach Anspruch 21, wobei der Vorprozessor ferner so betrieben werden kann, dass er das Gesicht zentriert.
- 35
25. Vorrichtung nach Anspruch 21, wobei der Vorprozessor ferner so betrieben werden kann, dass er das Gesicht ausschneidet.
- 35
26. Vorrichtung nach Anspruch 21, wobei der Vorprozessor ferner so betrieben werden kann, dass er eine Entfernung der weichen Regionen durch Anwendung einer geodätischen Maske durchführt.
- 40
27. Vorrichtung nach Anspruch 17, wobei der geodätische Konverter so betrieben werden kann, dass er das Fast-Marching-Verfahren für triangulierte Bereiche verwendet, um die geodätischen Entfernungen zu berechnen.
- 40
28. Vorrichtung nach Anspruch 17, ferner umfassend einen Triangulator (14) zum Bilden der triangulierten Mannigfaltigkeit aus Abtastdaten eines geometrischen Körpers.
- 45
29. Vorrichtung nach Anspruch 28, die ferner so betrieben werden kann, dass sie die triangulierte Mannigfaltigkeit in einen Raum von mehr als zwei Dimensionen einbettet, um **dadurch** zusätzliche Informationen mit den topografischen Informationen aufzunehmen.
- 50
30. Vorrichtung nach Anspruch 29, wobei die zusätzlichen Informationen beliebige aus einer Gruppe sind, die Texturinformationen, Albedo-Informationen, Graustufeninformationen und Farbinformationen umfasst.
- 50
31. Vorrichtung nach Anspruch 17, wobei der Unterabtaster (18) einen Optimierer umfasst, um einem Anwender zu ermöglichen, ein optimales Unterabtastungsniveau durch Definieren eines Kompromisses zwischen Berechnungskomplexität und Darstellungsgenauigkeit auszuwählen.
- 55
32. Vorrichtung nach Anspruch 17, wobei der multidimensionale Skalierer derart konfiguriert ist, dass die euklidische Darstellung eine vorgegebene Anzahl von Eigenwerten umfasst, die extrahiert werden können, um als Koordinaten in einem Merkmalsraum zu dienen.

33. Vorrichtung nach Anspruch 32, wobei die vorgegebene Anzahl von Eigenwerten wenigstens drei beträgt, und der Merkmalsraum eine Anzahl von Dimensionen aufweist, die der vorgegebenen Anzahl entspricht.

5 34. Vorrichtung nach Anspruch 9, ferner zum Ausschneiden einer Darstellung des Gesichts zur elektronischen Verarbeitung, wobei das Gesicht ferner wenigstens einen Zwischenmundöffnungszustand zwischen den offenen und den geschlossenen Zuständen aufweist, und die Vorrichtung umfasst:

10 eine erste Maskeneinheit zum Auswählen einer ersten geodätischen Kontur um einen invarianten Bezugspunkt auf dem Gesicht und Festlegen einer Region innerhalb der ersten geodätischen Kontur als eine erste Maske, eine zweite Maskeneinheit zum Auswählen einer zweiten geodätischen Kontur um eine Grenze der identifizierten Mundregion herum und Festlegen einer Region innerhalb der zweiten geodätischen Kontur als eine zweite Maske, und
 15 eine dritte Maskeneinheit zum Bilden einer Endmaske aus einer Vereinigung der ersten Maske und der zweiten Maske, um **dadurch** einen derartigen Ausschnitt des Gesichts bereitzustellen, dass eine vollständige Gesichtsregion und ein vernachlässigbarer Hintergrund innerhalb des Ausschnitts für jeden der Mundöffnungszustände erhalten wird.

20 **Revendications**

1. Procédé de fourniture d'une représentation électronique d'un visage comportant une bouche et capable d'adopter des états de bouche ouverte et de bouche fermée, pour le traitement électronique du visage, le procédé étant **caractérisé en ce qu'il** consiste à :

25 identifier une région de bouche dans ledit visage ;
 appliquer une contrainte topologique à ladite région de bouche ; et
 représenter ledit visage avec ladite contrainte, pour rendre de ce fait ladite représentation invariante par rapport à un état de bouche ouverte ou fermée respectif.

30 2. Procédé selon la revendication 1, dans lequel ladite contrainte topologique est sélectionnée de sorte qu'un contour géodésique se propage autour de ladite région de bouche sur un trajet sensiblement similaire indépendamment du fait que ledit visage est dans un état de bouche ouverte ou un état de bouche fermée.

35 3. Procédé selon la revendication 2, dans lequel ladite contrainte topologique comprend l'établissement de ladite région de bouche dans un état en permanence ouvert.

4. Procédé selon la revendication 3, dans lequel l'établissement de ladite région de bouche dans un état en permanence ouvert comprend un détournement autour de ladite région de bouche.

40 5. Procédé selon la revendication 2, dans lequel ladite contrainte topologique comprend l'établissement de ladite région de bouche dans un état en permanence fermé.

6. Procédé selon la revendication 1, dans lequel ladite identification d'une région de bouche comprend l'identification des lèvres.

45 7. Procédé selon la revendication 6, dans lequel ladite identification des lèvres comprend un traitement de texture.

8. Procédé selon la revendication 1, comprenant le détournement dudit visage en :

50 sélectionnant un premier contour géodésique autour d'un point de référence invariant sur ledit visage, établissant une région dans ledit premier contour géodésique en tant que premier masque, sélectionnant un deuxième contour géodésique autour d'une frontière de ladite région de bouche identifiée, établissant une région dans ledit deuxième contour géodésique en tant que deuxième masque, et formant un masque final à partir d'une union dudit premier masque et dudit deuxième masque.

55 9. Dispositif pour fournir une représentation électronique d'un visage comportant une bouche et capable d'adopter un état d'ouverture de bouche comprenant au moins un état de bouche ouverte et un état de bouche fermée, pour un traitement électronique du visage, le dispositif étant **caractérisé par** :

EP 1 849 122 B1

un élément d'identification de région de bouche pour identifier une région de bouche dans ledit visage (figure 5) ; et

une unité d'application de contrainte pour appliquer une contrainte topologique à ladite région de bouche (figure 6),

le dispositif étant configuré pour appliquer ladite contrainte à une représentation dudit visage, pour rendre de ce fait ladite représentation invariante par rapport à un état d'ouverture de bouche respectif.

10. Dispositif selon la revendication 9, dans lequel ladite contrainte topologique est sélectionnée de sorte qu'un contour géodésique se propage autour de ladite région de bouche sur un trajet sensiblement similaire indépendamment dudit état d'ouverture de bouche.

11. Dispositif selon la revendication 10, dans lequel ladite contrainte topologique comprend l'établissement de ladite région de bouche dans un état en permanence ouvert.

12. Dispositif selon la revendication 11, dans lequel l'établissement de ladite région de bouche dans un état en permanence ouvert comprend un détournement autour de ladite région de bouche.

13. Dispositif selon la revendication 10, dans lequel ladite contrainte topologique comprend l'établissement de ladite région de bouche dans un état en permanence fermé.

14. Dispositif selon la revendication 9, dans lequel ladite identification d'une région de bouche comprend l'identification des lèvres.

15. Dispositif selon la revendication 14, dans lequel ladite identification des lèvres comprend un traitement de texture.

16. Dispositif selon la revendication 9, comprenant en outre une unité de détournement pour détourer ledit visage, ladite unité de détournement comprenant :

une première unité de masque pour sélectionner un premier contour géodésique autour d'un point de référence invariant sur ledit visage, et établir une région dans ledit premier contour géodésique en tant que premier masque, une deuxième unité de masque pour sélectionner un deuxième contour géodésique autour d'une frontière de ladite région de bouche identifiée, et établir une région dans ledit deuxième contour géodésique en tant que deuxième masque, et

une troisième unité de masque pour former un masque final à partir d'une union dudit premier masque et dudit deuxième masque.

17. Dispositif selon la revendication 9, comprenant :

un convertisseur géodésique (20), pour recevoir des données topographiques tridimensionnelles dudit corps géométrique en tant que variété triangulée, et pour convertir ladite variété triangulée en une série de distances géodésiques entre des paires de points de ladite variété, et

un élément de mise à l'échelle multidimensionnel (22), connecté par la suite audit convertisseur géodésique, pour former une représentation euclidienne à faibles dimensions de ladite série de distances géodésiques, ladite représentation euclidienne à faibles dimensions fournissant une représentation invariante à la flexion dudit corps géométrique appropriée pour une mise en correspondance avec d'autres formes géométriques, ledit convertisseur géodésique et ledit élément de mise à l'échelle multidimensionnel étant tous deux situés avant ledit élément d'identification de région de bouche.

18. Dispositif selon la revendication 17, comprenant en outre un sous-échantillonneur (18) situé avant ledit convertisseur géodésique, configuré pour sous-échantillonner ladite variété triangulée, et pour fournir audit convertisseur géodésique une variété triangulée sous-échantillonnée.

19. Dispositif selon la revendication 18, dans lequel ladite variété comprend une pluralité de sommets, et dans lequel ledit sous-échantillonneur peut être mis en oeuvre pour sélectionner un premier sommet et pour sélectionner de manière itérative un sommet suivant ayant une distance géodésique la plus grande par rapport aux sommets déjà sélectionnés, jusqu'à ce qu'un nombre prédéterminé de sommets ait été sélectionné.

20. Dispositif selon la revendication 19, dans lequel ledit sous-échantillonneur peut être mis en oeuvre pour utiliser le

procédé de Fast Marching pour les domaines triangulés pour calculer des distances géodésiques entre les sommets pour ladite sélection itérative.

- 5 **21.** Dispositif selon la revendication 18, dans lequel ledit corps géométrique est un visage, comportant des régions géométriques souples, qui sont des régions dudit visage susceptibles de présenter des changements géométriques à court terme, et des régions géométriques dures, qui sont des régions sensiblement peu susceptibles de présenter des changements géométriques à court terme, ledit dispositif comprenant un préprocesseur (16), situé avant ledit sous-échantillonneur, pour retirer lesdites régions géométriques souples dudit visage.
- 10 **22.** Dispositif selon la revendication 21, dans lequel ledit préprocesseur peut être mis en oeuvre pour identifier lesdites régions souples par l'identification d'un point d'orientation sur ledit visage.
- 23.** Dispositif selon la revendication 22, dans lequel ledit point d'orientation est au moins l'un d'un bout de nez, d'une paire de centres de globes oculaires et d'un centre de bouche.
- 15 **24.** Dispositif selon la revendication 21, dans lequel ledit préprocesseur peut en outre être mis en oeuvre pour centrer ledit visage.
- 25.** Dispositif selon la revendication 21, dans lequel ledit préprocesseur peut en outre être mis en oeuvre pour détourner ledit visage.
- 20 **26.** Dispositif selon la revendication 21, dans lequel ledit préprocesseur peut être mis en oeuvre pour effectuer le retrait desdites régions souples par l'application d'un masque géodésique.
- 25 **27.** Dispositif selon la revendication 17, dans lequel ledit convertisseur géodésique peut être mis en oeuvre pour utiliser le procédé de Fast Marching pour les domaines triangulés pour calculer lesdites distances géodésiques.
- 28.** Dispositif selon la revendication 17, comprenant en outre un élément de triangulation (14) pour former ladite variété triangulée à partir de données de balayage d'un corps géométrique.
- 30 **29.** Dispositif selon la revendication 28, pouvant en outre être mis en oeuvre pour intégrer ladite variété triangulée dans un espace de plus de deux dimensions, pour inclure de ce fait des informations supplémentaires avec lesdites informations topographiques.
- 35 **30.** Dispositif selon la revendication 29, dans lequel lesdites informations supplémentaires sont des informations quelconques d'un groupe comprenant des informations de texture, des informations d'albedo, des informations d'échelle de gris et des informations de couleur.
- 31.** Dispositif selon la revendication 17, dans lequel ledit sous-échantillonneur (18) comprend un optimiseur pour permettre à un utilisateur de sélectionner un niveau de sous-échantillonnage optimal en définissant un compromis entre une complexité de calcul et une précision de représentation.
- 40 **32.** Dispositif selon la revendication 17, dans lequel ledit élément de mise à l'échelle multidimensionnel est configuré de sorte que ladite représentation euclidienne comprenne un nombre prédéterminé de valeurs propres pouvant être extraites pour être utilisées en tant que coordonnées dans un espace de caractéristique.
- 45 **33.** Dispositif selon la revendication 32, dans lequel ledit nombre prédéterminé de valeurs propres est au moins égal à trois, et ledit espace de caractéristique a un certain nombre de dimensions correspondant audit nombre prédéterminé.
- 50 **34.** Dispositif selon la revendication 9, pour détourner en outre une représentation dudit visage pour un traitement électronique, ledit visage ayant en outre au moins un état d'ouverture de bouche intermédiaire entre lesdits états ouvert et fermé, le dispositif comprenant :
- 55 une première unité de formation de masque pour sélectionner un premier contour géodésique autour d'un point de référence invariant sur ledit visage, et établir une région dans ledit premier contour géodésique en tant que premier masque,
une deuxième unité de formation de masque pour sélectionner un deuxième contour géodésique autour d'une

EP 1 849 122 B1

frontière de ladite région de bouche identifiée, et établir une région dans ledit deuxième contour géodésique en tant que deuxième masque, et
une troisième unité de formation de masque pour former un masque final à partir d'une union dudit premier masque et dudit deuxième masque, pour réaliser de ce fait un détournement dudit visage de manière à obtenir une région faciale complète et un arrière-plan négligeable dans ledit détournement pour l'un quelconque desdits états d'ouverture de bouche.

5

10

15

20

25

30

35

40

45

50

55

Fig. 1B

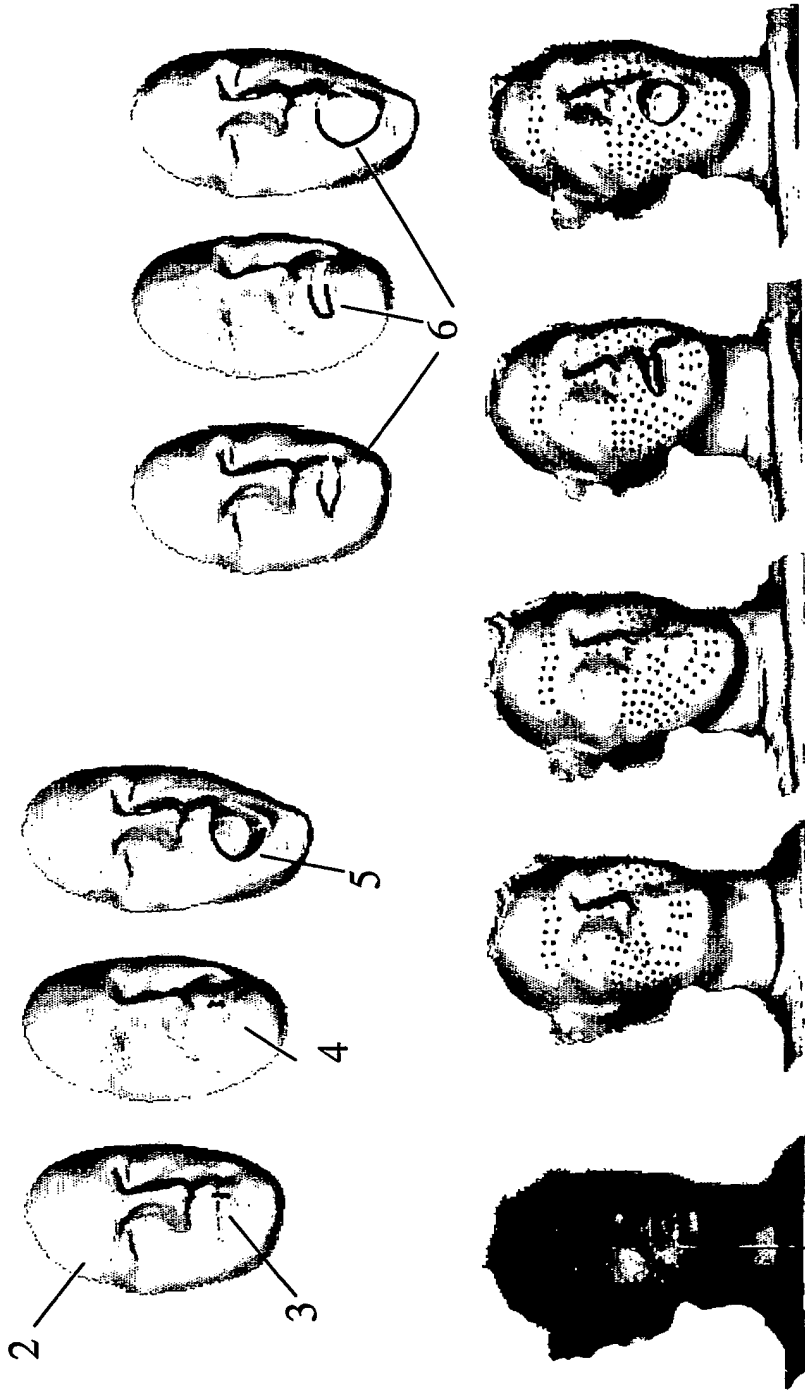


Fig. 1C

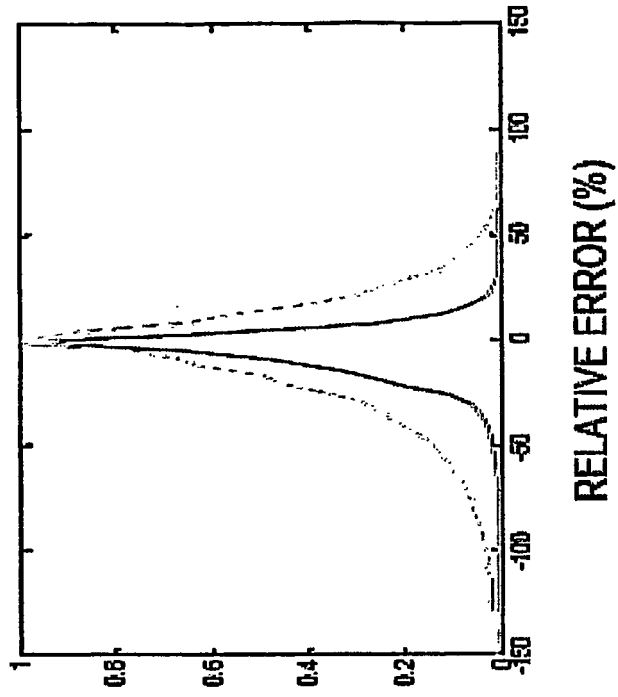


Fig. 1E

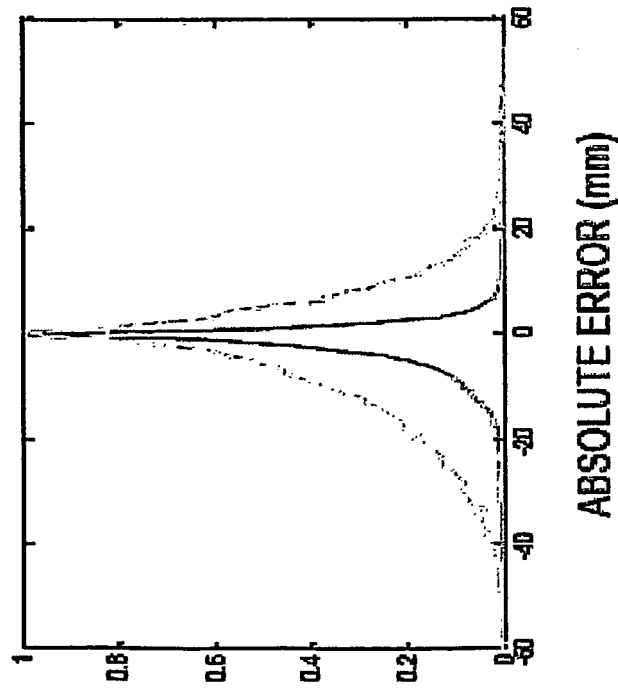
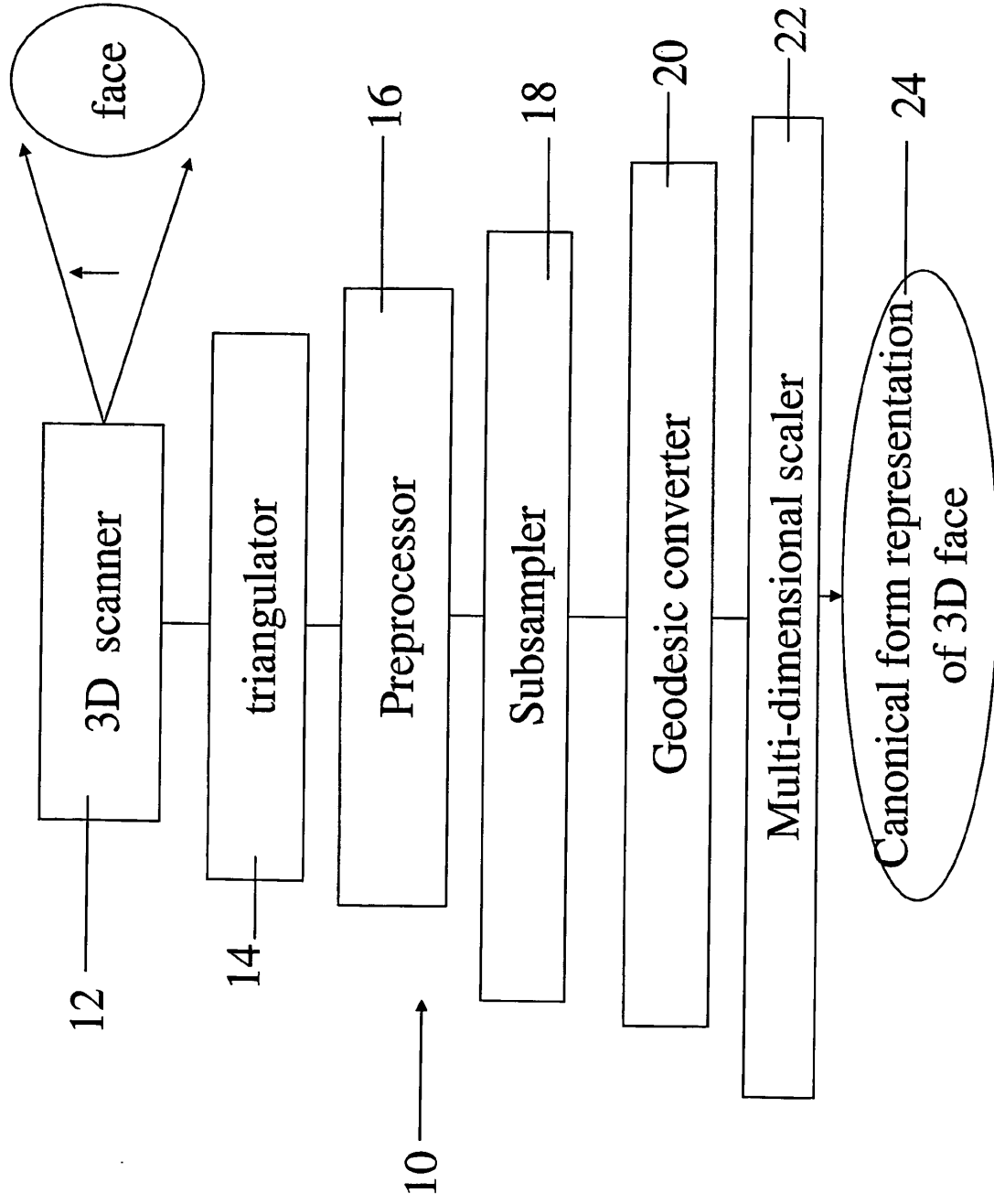


Fig. 1D

Fig.2A



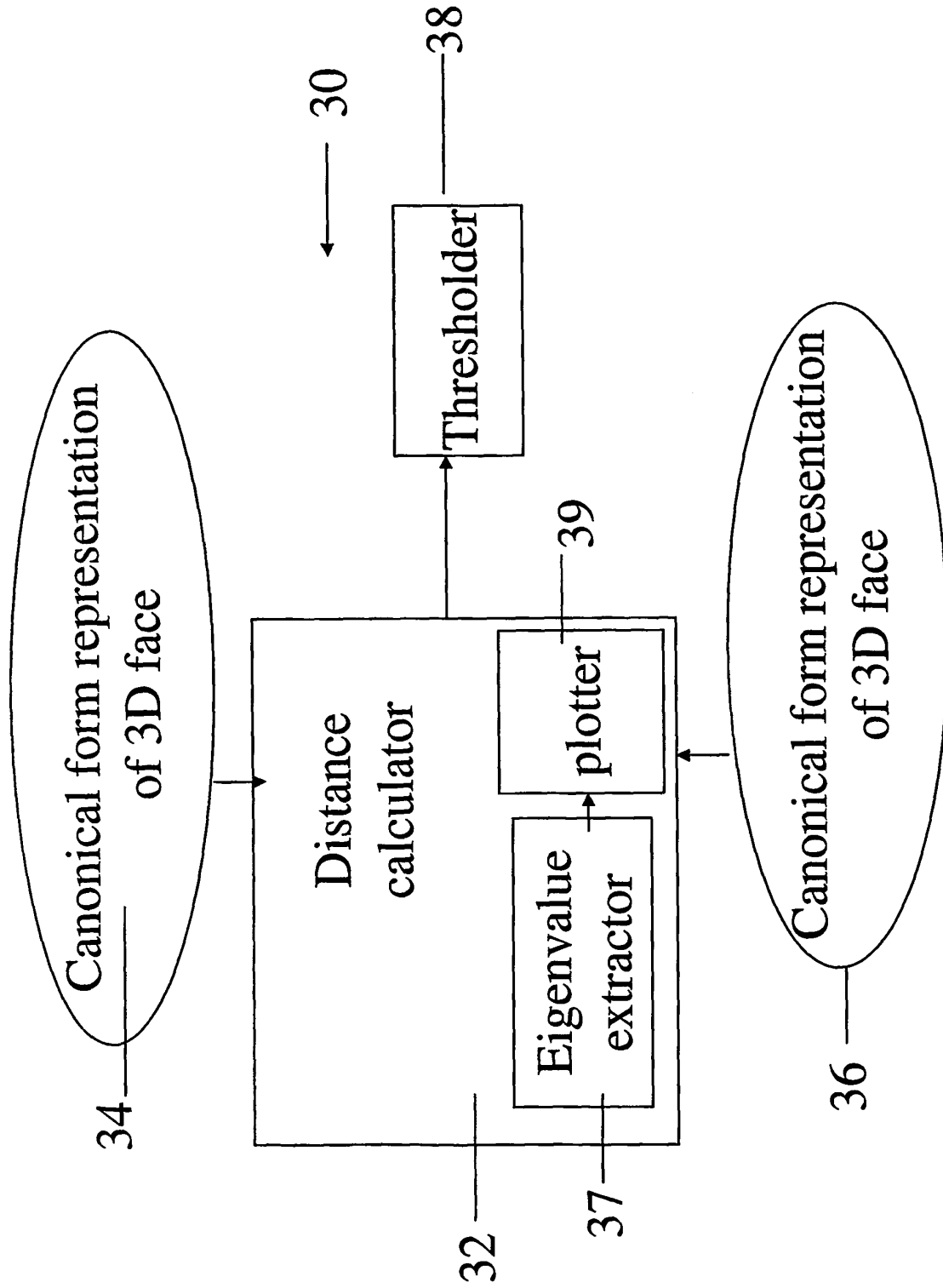


Fig. 2B

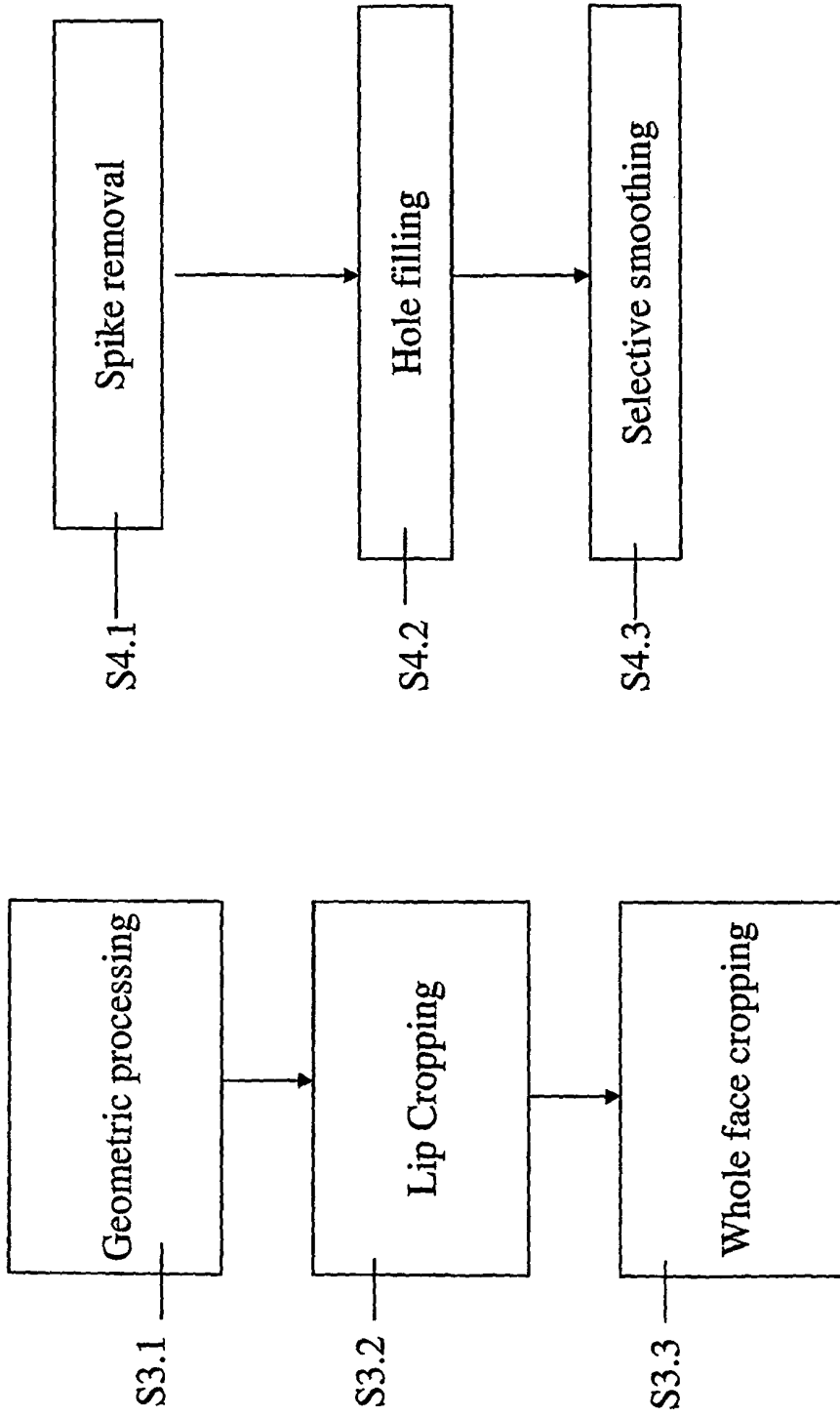


Fig. 4

Fig. 3

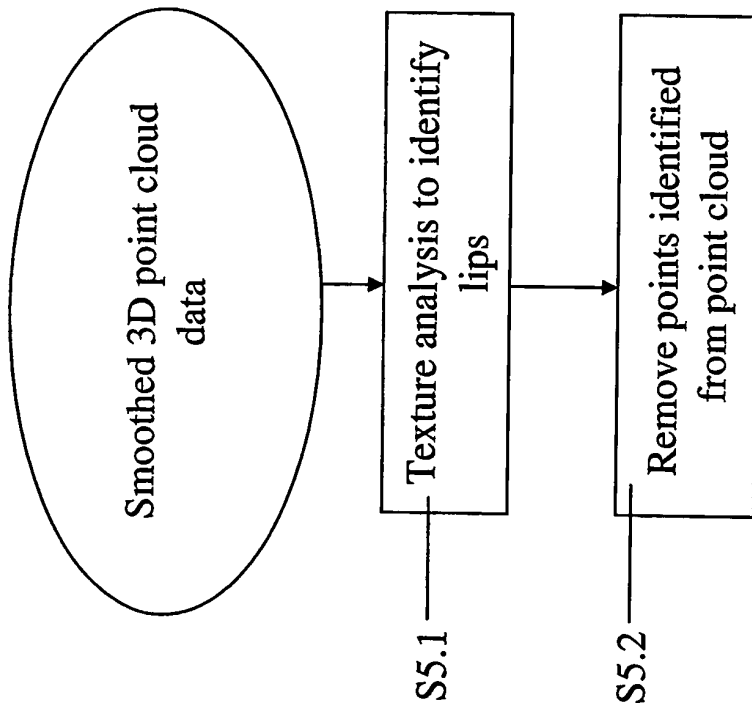


Fig. 5

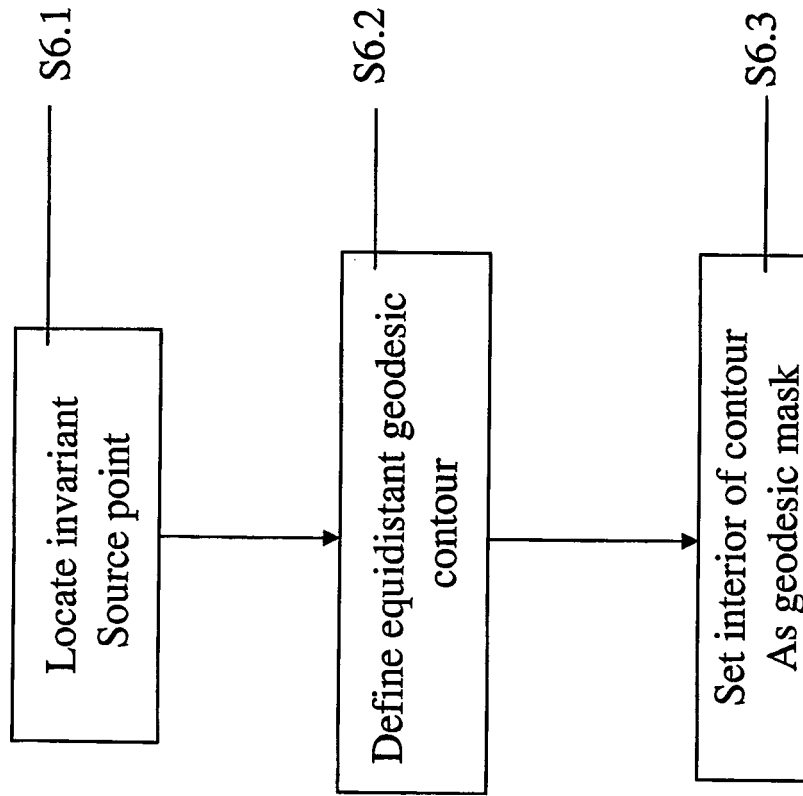


Fig. 6

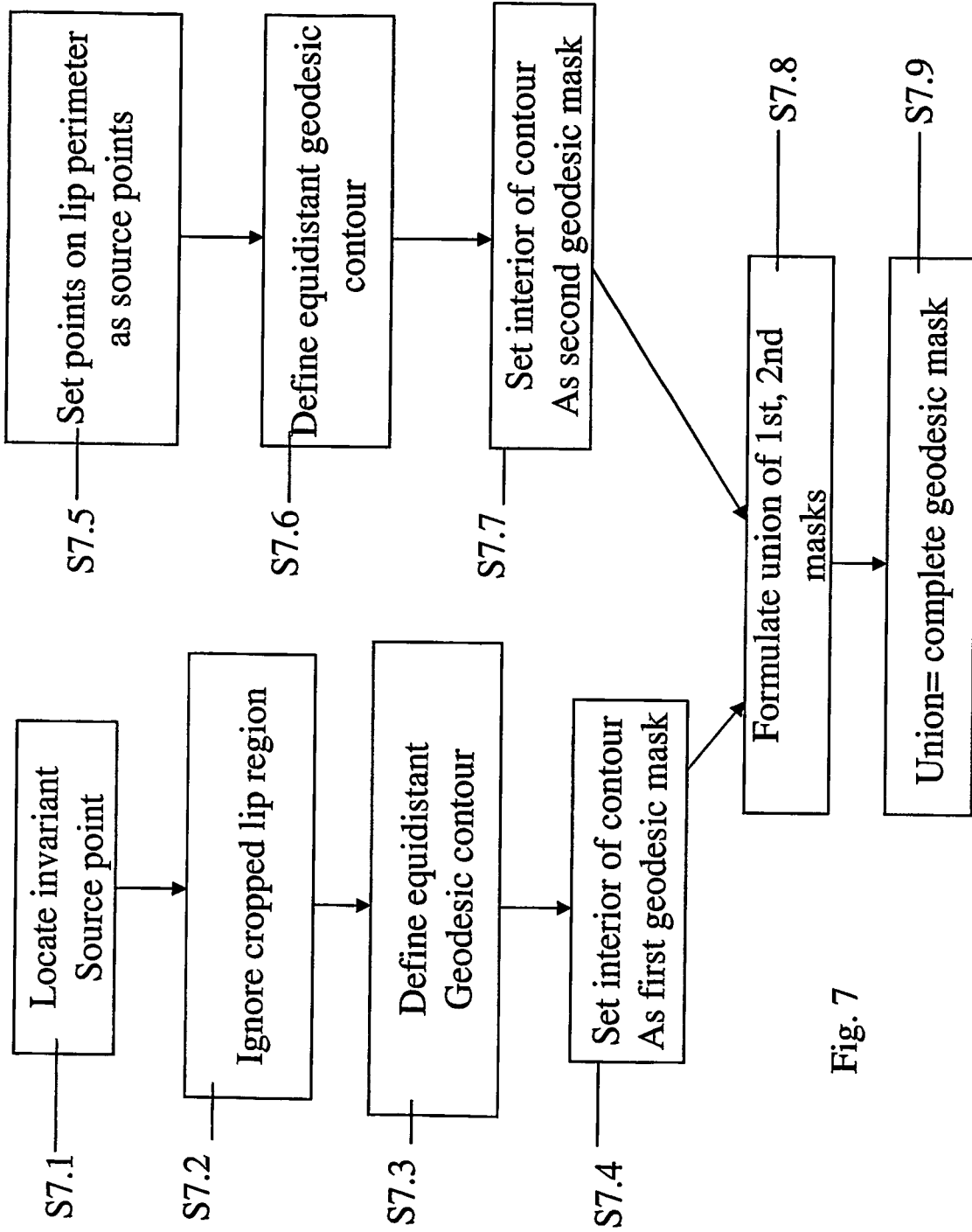


Fig. 7

60

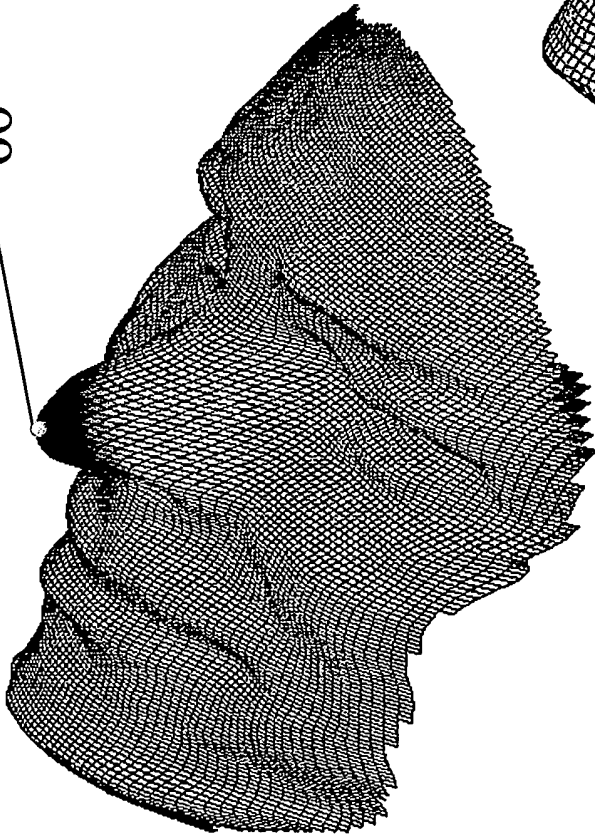


Fig. 8

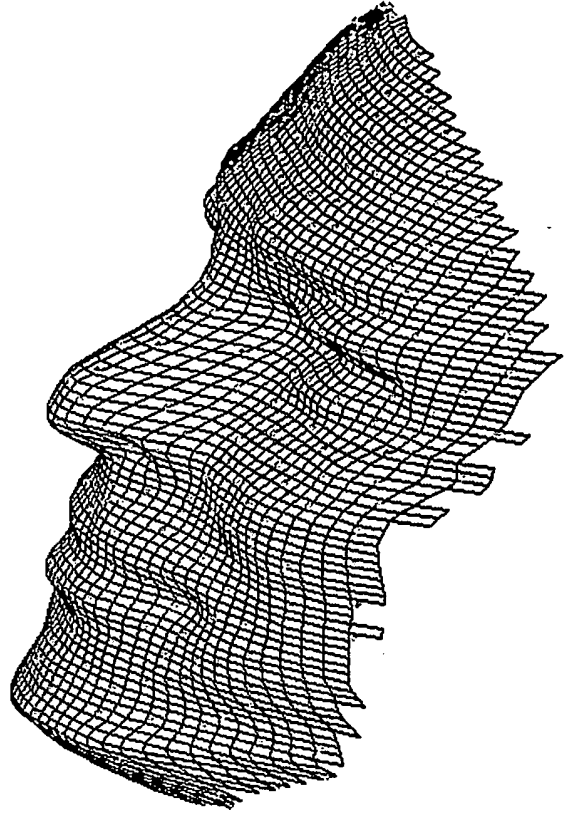


Fig. 9

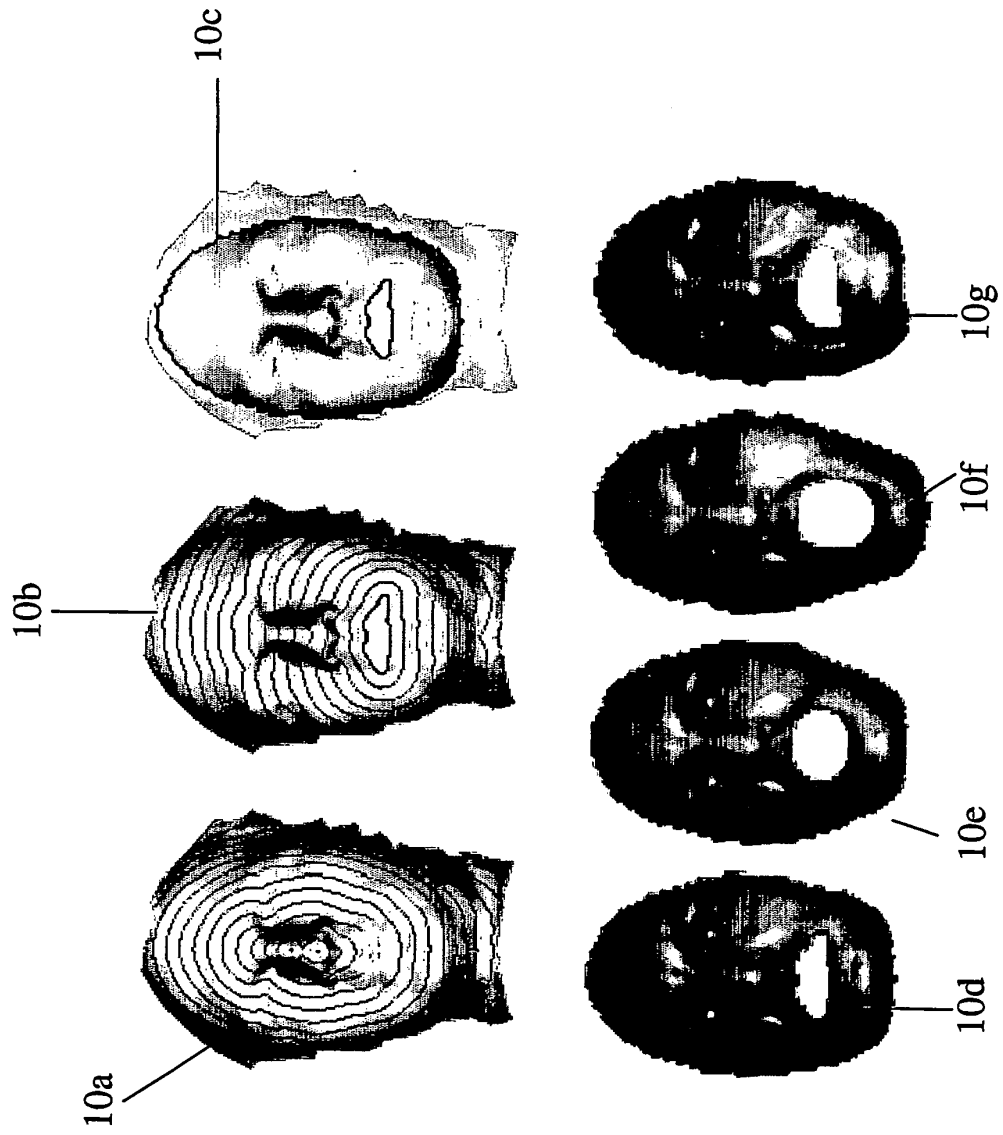


Fig. 10

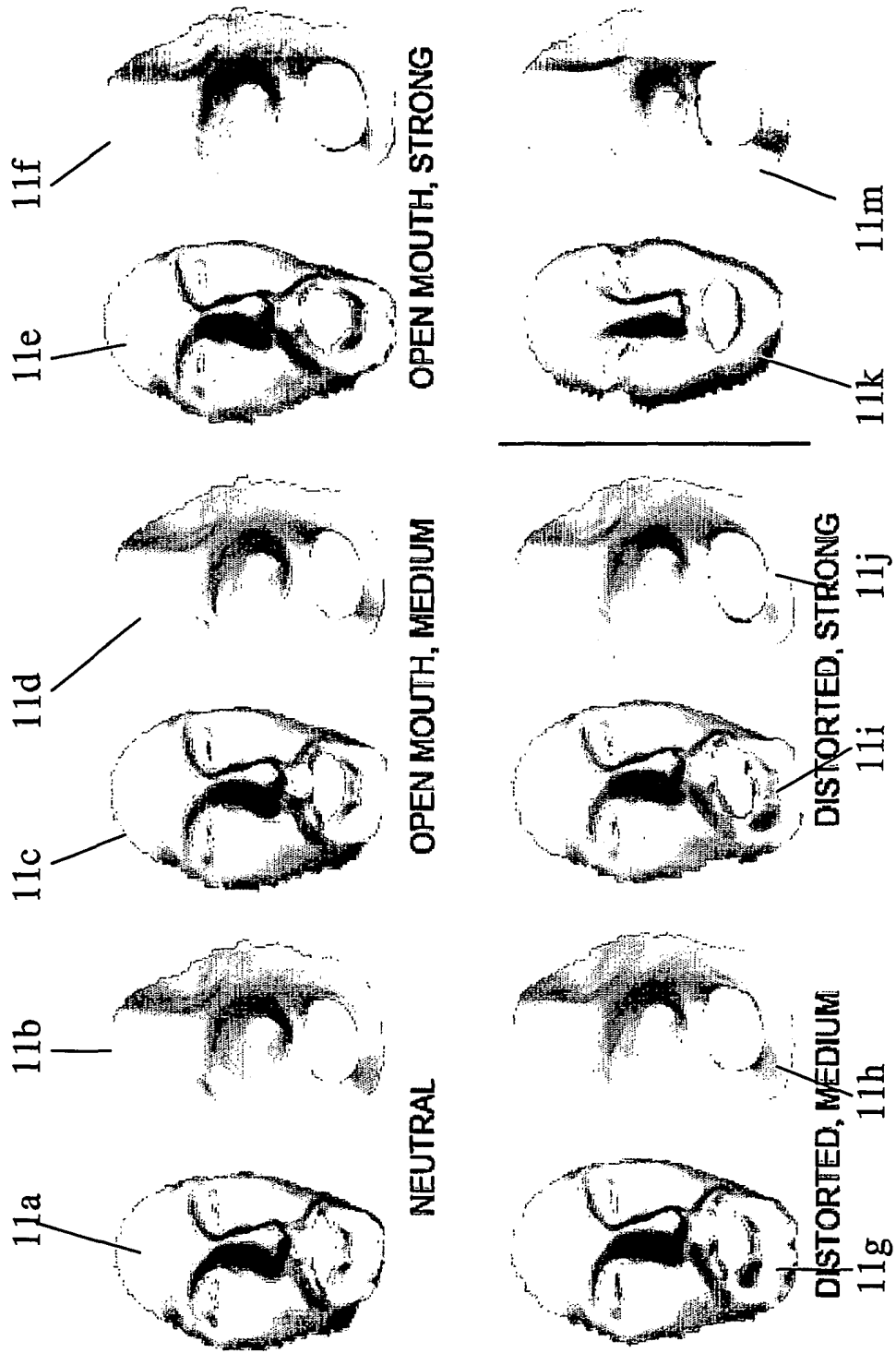


Fig. 11

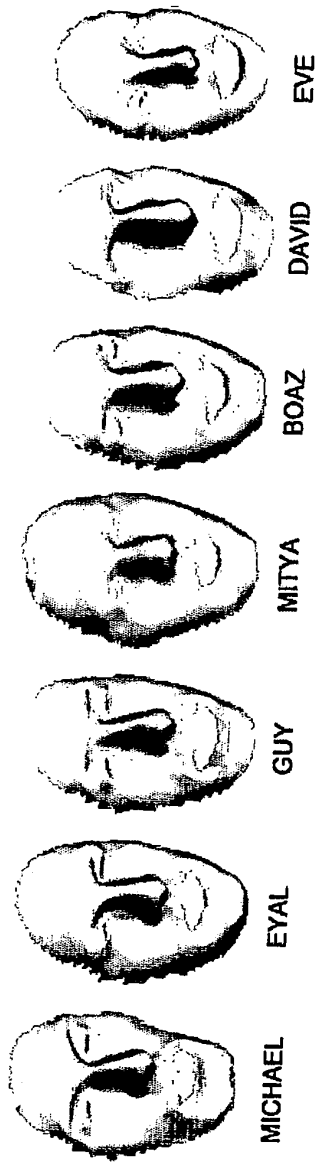


Fig. 12

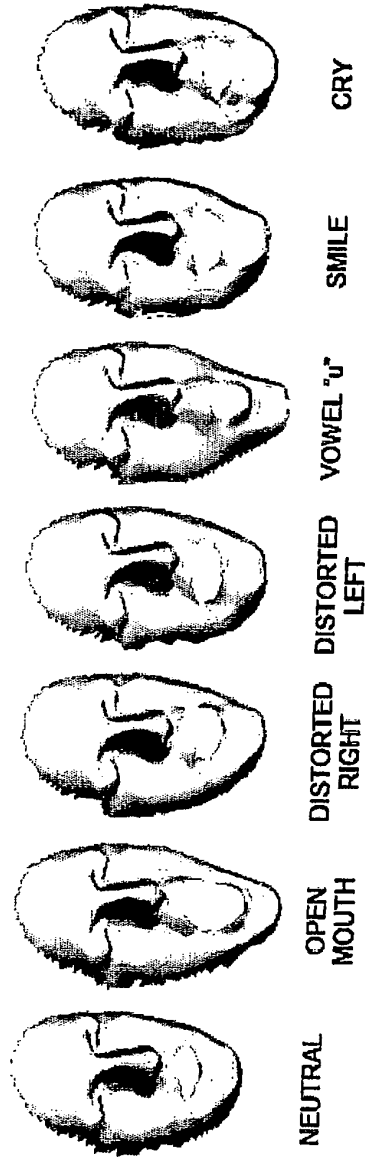


Fig. 13

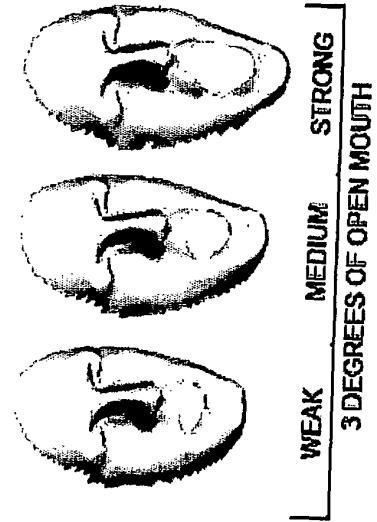


Fig. 14

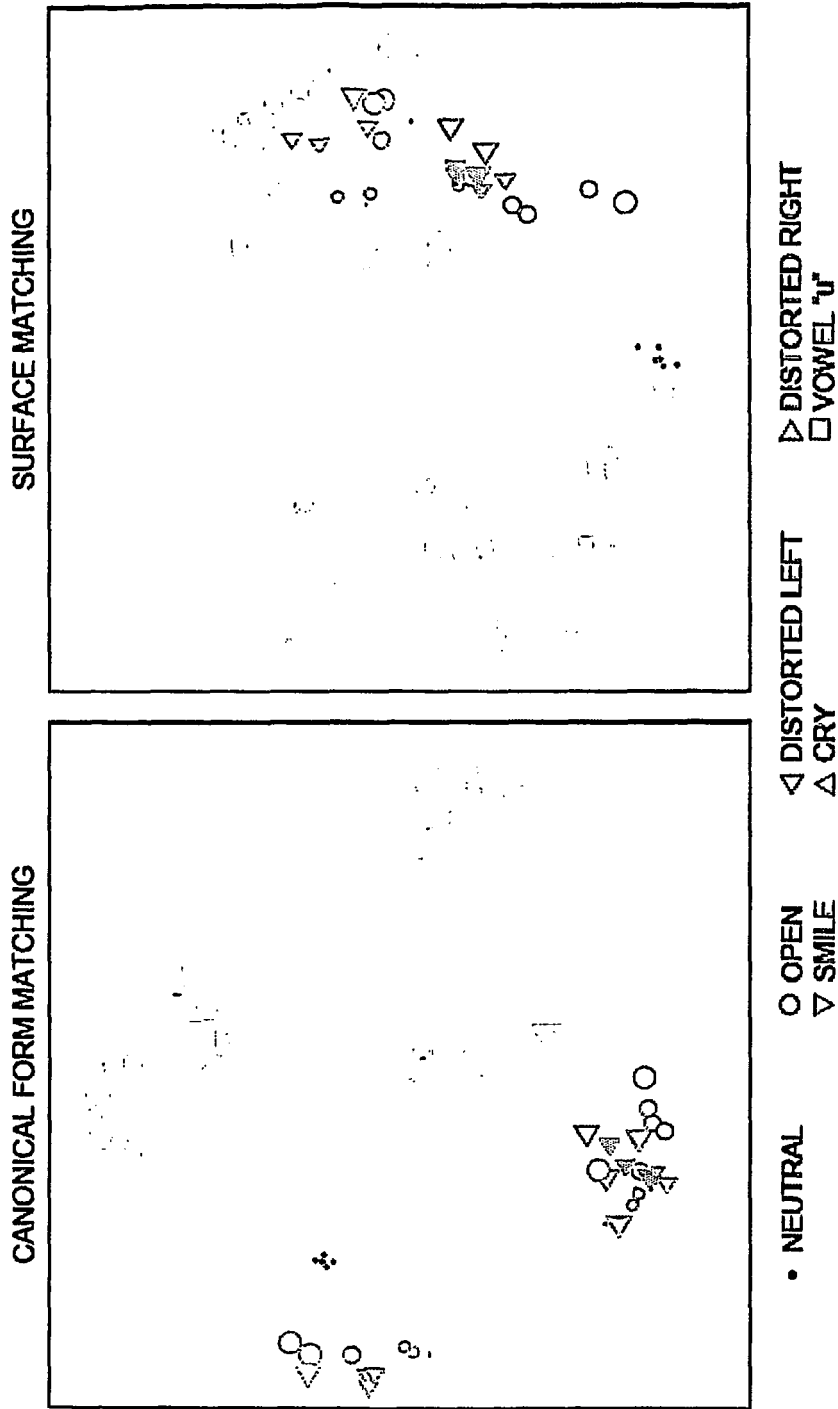


Fig. 15B

Fig 15A

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- WO 2004032061 A [0006]
- WO 2004044689 A [0007]
- US 10284281 B [0070]

Non-patent literature cited in the description

- **R. Kimmel ; J. A. Sethian.** Computing geodesic on manifolds. *Proc. US National Academy of Science*, 1998, vol. 95, 8431-8435 [0063]
- **M. Bronstein ; A. Bronstein ; R. Kimmel.** Three-dimensional face recognition. *Technical Report CIS-2004-04, Dept. of Computer Science, Technion, Israel*, 2003 [0068]
- **I. Borg ; P. Groenen.** Modern multidimensional scaling - theory and applications. Springer-Verlag, 1997 [0081]
- Applications of convex analysis to multidimensional scaling. **J. De-Leeuw.** Recent developments in statistics. 1977, 133-145 [0081]