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(71) Applicant *(for all designated States except US)*: **OMNIPERCEPTION LIMITED** [GB/GB]; 20 Nugent Road, Surrey Research Park, Guildford, Surrey GU2 7AF (GB).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **KITTLER, Josef** [GB/GB]; 78 The Street, Shalford, Guildford GU4 8BU (GB). **ZOU, Xuan** [CN/CN]; Flat 1102, N°55, 578 Xiang Yin Road, Shanghai 200433 (CN). **TENA, Jose, Rafael** [MX/GB]; Centre for Vision Speech and Signal Processing, University of Surrey, Guildford, Surrey GU2 7XH (GB). **HANCOCK, Peter** [GB/GB]; 59 Allanvale Road, Bidge of Allan, Stirling FK9 4PA (GB). **MCINTYRE, Alexandra, Helen** [GB/GB]; 3 James Boyle Square, Milton of Campsie, East Dunbartonshire G66 8JN (GB). **MESSER, Kieron** [GB/GB]; 30A Barrack Road, Guildford, Surrey GU2 9RU (GB).

(74) Agent: **BIBBY, William, Mark**; MATHISEN, MACARA & CO., The Coach House, 6-8 Swakeleys Road, Ickenham, Uxbridge, Middlesex UB10 8BZ (GB).

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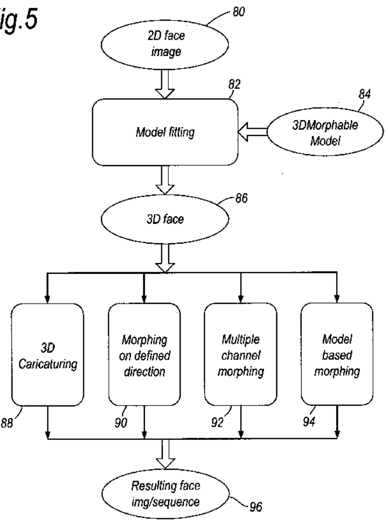
Fig.5



(57) Abstract: A method for recognition of a subject's face is described. The method processes image data of a subject's face, then processes the image data to produce a morphed image which can be presented for recognition. Also described are a related system and computer program product for recognition of a subject's face.

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A SYSTEM AND METHOD FOR FACIAL RECOGNITION

This invention relates to a method and system for facial recognition of a subject's face and the related computer program product.

Automatic face recognition has been a very active research area recently with a notable progress achieved for various applications in controlled environments. This is described in detail in *P. J. Phillips et al FRVT 2006 and ICE 2006, large scale results. Technical report NIST 2007.* Nevertheless, the involvement of human operators in the task of face recognition is still necessary. One of the reasons for this is the relatively poor performance of automatic face recognition in uncontrolled scenarios where the captured face to be recognised is captured under poor illumination conditions, captured in an unfamiliar pose, captured with a different expression to the reference image it is to be compared with, or is acquired at a low resolution. Thus, automatic face recognition systems have not been fully deployed in all the places where frequent face identity checks are needed, such as the airport or border controls for example. Moreover, there are specific scenarios which cannot be performed automatically and require human operators, for example, virtual identity parades where a witness is asked to identify suspects from a group of candidates, as in forensic face matching. Clearly, the witness is a fundamental requirement and could not be replaced by a machine.

Psychological studies have shown that face recognition that is performed by a human is a task that is more difficult than one would think. People generally need excessive effort and time to recognize unfamiliar faces or images that have been captured in poor condition as described above. Moreover, human operators may easily get tired and this may lead to low efficiency and mistakes in face recognition.

Human judgement is also disproportionally affected by superficial and external distractions such as a difference in face image colour tinge, in pose, or hairstyle, for example. Typically, human operators are requested to identify a query face from a subset of candidate's faces selected either manually or by an automatic face recognition system, by their very definition the subset of candidate's faces will tend to be similar. The operator is then more likely to be confused by the apparent similarity among these candidates' faces. Such an example of a face to be recognised along with ten possible candidate images is shown in Figure 1. This is described in more detail later.

For these reasons, a system, method and computer program product to help human operators make face recognition decisions effectively and reliably would be of great benefit.

According to the invention there is provided a method of human recognition of a subject's face comprising the steps of producing image data representing a morphable image of the subject's face; processing said image data to produce a morphed image of the subject's face and presenting said morphed image for recognition.

It will be understood that the term recognition herein embraces the process of matching a subject's face to one or more reference image.

According to the invention there is also provided a facial image processing system for presenting an image of the subject's face for recognition of said subject comprising, acquisition means for acquiring image data representing a morphable image of the subject's face; processing means for processing said image data to produce a morphed image of the subjects face; presentation means for presenting said morphed image for recognition of said subject.

According to the invention there is further provided a computer program product for use in facial recognition of a subject's face comprising; machine readable media having recorded thereon programming instructions for causing a computer system to: acquire image data representing; a morphable image of the subject' face; process said image data to produce a morphed image of the subject's face; and present said morphed image for recognition.

Many interesting facts regarding how humans perceive and recognize faces have been discovered by the psychologists in the past decade. These are described in detail in *Alice J O'Toole, "Psychological and neural perspectives of human face recognition". In Stan Li and Anil K. Jain, editors, Handbook of face recognition. Springer, 2004* and *P. Sinha, B. Balas, Y. Ostrovsky, and R. Russell. "Face recognition by humans: Nineteen results all computer vision researchers should know about". Proceeding of the IEEE, 94 (11): 1948-1962, 11 2006.*

As far as the Inventors are aware there is currently no commercially available system specifically designed to effectively assist human operators to perform the task of face recognition. Commercial face manipulation software systems currently available are commonly designed for face animation, and do not have the necessary features required for face analysis and face matching.

The method, system and computer program product to be described herein focus on applying image morphing techniques to acquired face images of a subject to help recognition of the acquired image by a human. This is generally done by processing image data obtained from the face image of the subject After caricaturing of the image (caricaturing is a specific morphing technique), a face can generally be more easily recognised by a human. Other morphing techniques also make a face easier to recognise.

The image morphing technique developed for this system is based on the 3D face morphing process. The technique involves fitting a generic 3D face morphable model to image data representing a 2D face image of a subject to obtain image data representing a morphable 3D face of the image of the subject, which can then be processed by morphing on the shape channel and the texture channel, either separately or together. The 3D face morphing process, to be described later, facilitates 3D face caricaturing, and this provides considerably more information than 2D face morphing for a human operator, in the sense that a face with a new pose, under different illumination and improved resolution can be generated when the 3D information is available. This change in pose, resolution and illumination is generally not available if the image of the subject is morphed by a 2D process only.

Embodiments of the invention will now be described by way of example only, with reference to the accompanying drawings of which:

Figure 1 shows an example of a human recognition task;

Figure 2 shows an example of a human recognition task with the subject in an alternative pose;

Figure 3 shows 3D face morphing along a line connecting an average face and a specific face;

Figure 4 shows a statistical shape model and statistical texture model of a 3D face;

Figure 5 is a diagram of a 3D morphing system;

Figure 6 shows fitting a 3D morphable model to a 2D face to obtain a 3D face of the subject;

Figure 7 shows morphing from a male face to a female face on the shape and texture channel;

Figure 8 shows morphing a male face to a female face on the shape channel only;

Figure 9 shows morphing a male face to a female face on the texture channel only;

Figure 10 shows morphing the average face by varying the first coefficient of the shape model but retaining the texture coefficient;

Figure 11 shows morphing the average face in the texture channel along the direction defined by two female faces with different skin colour.

As mentioned earlier, Figure 1 shows an example of a human recognition task. The task is to match the query face (10) in the top row with one of the ten possible candidates (20A .....20J) in the array of gallery images below. More details of this particular task are described in *Vicki Bruce, Zo Henderson, Karen Greenwood, Peter J. B. Hancock, A. Mike Burton, and Paul Miller. Verification of face identities from images captured on video. Journal of Experimental Psychology: Applied, 5:339-360,1999.*

Figure 2 (also described in *Bruce et al*) shows a recognition task where the subject to be identified (12) is given an unfamiliar pose. Again, the subject should be matched with one of ten candidate faces (20A.....20J) in the array of gallery images below. In this case recognition of the face by a human is generally more difficult, due to the unfamiliar pose of the subject to be identified.

By manipulating the image data representing the image of subject to be recognised it is possible to produce a modified facial image of the subject which is generally easier for another human to recognise. The image data can be processed in such a way that the image of the subject to be recognised undergoes 2D image morphing and/or by 3D image morphing. Different types of image morphing will now be described.

Image Morphing is defined as the process in which one image changes to another through a seamless transition. This applies to many different sort of images, and not just faces. The traditional technique for 2D image morphing has matured over the last decade. *G. Wolberg. Image morphing: A survey. The Visual Computer,* *14:360-372, 1998* provides a survey on the advances of 2D image morphing techniques in terms of feature specification, warp generation methods and transition control.

A review of commercial software systems for 2D image morphing that are currently available on the market is provided at *http://morphing-software review.toptenreviews.com*, however, the products described in the review are largely developed for computer animation applications, not for face matching applications.

With the availability of 3D information, 3D image morphing has several advantages over 2D image morphing. In particular, it is easy to change the view point of the face, the particular facial illumination conditions and to deal with any facial occlusions that may be present in the 2D image.

The surface of a particular 3D object is described by a 3D shape map and a 2D texture map of the surface. The 3D shape map contains information about the 3D form of the face and is represented in terms of a mesh of vertices defined by their 3D coordinates, and how several vertices of the mesh form each cell of the mesh. The texture map is a colour image that captures the colour information of the surface.

Morphing from one 3D face to another 3D face can then be performed on the shape channel only, on the texture channel only, or simultaneously, on both the shape and texture channels.

Given two topologically similar 3D object surfaces, i.e. two surfaces with the same number of vertices, the morphing between these two surfaces can be performed as the interpolation between the coordinates of the corresponding vertices on each surface. The morphing on the 2D texture map is implemented by the interpolation between the corresponding pixel locations in the source images, which is just the same as in the Cross-dissolves method for 2D image morphing (The Cross-dissolves method is described in detail in the Wolberg reference mentioned previously.

Morphing between two topologically different 3D object surfaces is an interesting but challenging process. Before the morphing can be performed, 3D correspondence between the source and the target 3D surface has to be established by surface registration.

http://web.mit.edu/manoli/morph/www/morph.html, describes an example of morphing between two topologically different 3D object surfaces which involves mesh subdivision, union, and matching.

Among the available 3D animation software systems, there are some software systems specifically designed for 3D face animation, such as Facial Studio and FaceGen Modeler (*http://www.facegen.com*). FaceGen Modeller is able to generate various face effects based on a statistical 3D face model, and the software also has a function for 3D reconstruction of a face from a single 2D face image or from an orthogonal 2D face image pair. Again, these 3D animation software systems are developed specifically for face animation and cannot be applied directly for the purpose of assisting face matching by human operators.

An alternative image morphing process is that of face caricaturing. This is the process of generating a face caricature in which distinctive facial features are exaggerated. Previously face caricatures could only be created by an artist, but nowadays caricatures can be generated automatically by computers. Image morphing provides the means to perform face caricaturing. Representing a face as a vector of 2D facial feature points, 3D shape vector, intensity/colour measurements or model coefficients (as described later) a face is a point in a high dimensional space.

Mathematically the linear morphing along a line defined by two faces can be represented by:

$$M = S + \lambda (D - S) \qquad (1)$$

Where M is the resulting morphed face, S is a test average face from a set of reference images, D is the face of the subject to be recognised and λ is the morphing coefficient. The reference images are typically obtained by processing (in various different ways) a set of training images. However, they may be obtained without the use of training images. When S is the average face, M is a caricature of face D when $\lambda > 1$. The distinctive facial features in face D become more exaggerated in M when λ gets larger. In the direction opposite to the given real face ($\lambda < 0$), the morphing generates so-called anti-faces. Between the average face and the given face ($1 > \lambda > 0$), the morphing is called anti-caricaturing. This is described in more detail in *D. A. Leopold, A. J. O'Toole, T. Vetter, and V. Blanz. Prototype-referenced shape encoding revealed by high-level after-effects. Nature Neuroscience, 4(1):89-94, 2001.* An example of a 3D face morphing process is shown in Fig. 3. This Figure shows a range of faces for various values of λ. On the far left hand side of the Figure is a 3D anti-face (50), the third face along from the left hand side is an average 3D face (40), the third face from the right hand side (30) is a real face and between the average face and the real face the real face has undergone a series of anti-caricaturing steps to produce several intermediate faces (30A, 30B, 30C). The two faces (30AA, 60) on the right hand side of the Figure are caricatures of the real 3D face (30) in Figure 3.

The first automatic caricaturing system was proposed in *S. E. Brennan. Caricature generator: the dynamic exaggeration of faces by computer. Leonardo, 18(3): 170-178, 1985*, to generate 2D line drawn caricatures from photographs. Other caricaturing systems and related image processing systems are described in *Philip J. Benson and David I. Perrett. Synthesizing continuous-tone caricatures. Image Vision Comput., 9(2):123-129, 1991*, and *D. A. Rowland, D. I. Perrett, D. M. Burt, K .J. Lee, and S. Kamatsu. Transforming facial images in 2 and 3D. In Imagina 97-conference-ACES Proceedings, pages 159-175, 1997.* The techniques reviewed in these papers include how to generate average (prototype) image by averaging different face images, how to automatically exaggerate an individual face which is different in shape and colour from the prototype, and how to extend the technique to 3D caricaturing. For 3D caricaturing, different 3D acquisition methods have been adopted, and these are described in several publications including *V. Blanz and T. Vetter. A morphable model for the synthesis of 3D faces. In Proceedings of SIGGRAPH, 1999*; *T. Fujiwara, H. Koshimizu, K. Fujimura, G. Fujita, Y. Noguchi, and N. Ishikawa. A method for 3D face modelling and caricatured figure generation. In Proceedings of IEEE International Conference on Multimedia and Expo, 2002, pages 137-140, 2002; A. Shadbolt. From 2D photographs to 3D caricatures. Master's thesis, University of Sheffield, 2003*; and *Yu-Lun Chen, Wen-Hung Liao, and Pei-Ying Chiang. Generation of 3D caricature by fusing caricature images. In Proceedings of IEEE International Conference on Systems, Man and Cybernetics, pages 866-871, 2006.*

Although most computer generated caricatures are based on equation 1 (on page 8), recent work, in particular that of Chen, Liao and Chang referenced above and *L. Liang, H. Chen, Y. Q. Xu, and H. Y. Shum. "Example-based caricature generation with exaggeration". In Proceedings of 10th Pacific Conference on Computer Graphics and Application, pages 386-393, 2002*, focus on incorporating artist's style into the face caricature generation process.

The linear morphing described by equation 1 can be generalised to morphing a third face along any direction defined by two example faces. The new morphing is represented by:

$$M = D + \lambda (S1 - S2) \qquad (2)$$

Where S1 and S2 are two images from the set of reference images defining a morphing direction. When the direction between S1 and S2 carries specific holistic information, the resulting image M will represent the subject's face D, subject to the given holistic variation. For instance, when S1 and S2 are the average male face and the average female face, respectively, the morphing will carry changes related to gender change. Alternatively, S1 and S2 may represent average faces of different race, or of different ages, or any other identifiable cohort.

An alternative morphing process is statistical model based morphing. This is a method which makes use of the statistical information about an object class conveyed by its image. When the source image and the target images are images of objects in the same class, e.g. both images are faces, the morphing can be performed with the statistical model of the class.

The images or data representing the images are projected to a subspace spanned by a statistical model, e.g. Principle Component Analysis (PCA) subspace, and each image or image data is represented by projection coefficients. Morphing can then be performed by interpolation between the projection coefficients of the source image (or image data) and those of the target image (or image data). Each morphed image can then be reconstructed from the corresponding projection coefficients obtained by the interpolation process. Although the projection coefficients have been described here within reference to statistical model based morphing they may also be derived from all the other morphing processes described herein.

A statistical model of a 3D face usually consists of a statistical shape model and a statistical texture model, this is illustrated in more detail in Figure 4. The 3D face (70) to be modelled is shown on the left hand side of the Figure. Shape models (72a, 72b.......72n) are shown in the top row, alongside references A1, A2 etc..... The texture models (74a, 74b ......74n) are shown below alongside references B1, B2 etc. Statistical modelling provides a new way to manipulate the images. Each dimension of the model subspace captures different holistic information of the training samples form the object class.

P. Hancock, "Evolving faces from principal components". Behaviour Research Methods, Instruments and Computers, 32(2):327-333, 2000 describes a dataset for various coefficients of a 2D shape PCA model. The first coefficient of a 2D shape PCA model trained from this dataset codes the overall size of a face image, the second coefficient codes the face width, and the third coefficient codes the tilt of the head mixed in with a factor reflecting the relative width of the top and bottom part of the face. By varying the coefficient(s) in each dimension or several dimensions, the image reconstructed will undergo interesting global changes.

In most situations only 2D face images e.g. photographs, can be provided, as 3D face data is not as readily available as 2D face images. Instead of using traditional 2D image morphing to manipulate the face image that is provided a 3D model fitting technique can be applied to reconstruct a 3D face from the given 2D face images, then 3D morphing can be performed on the reconstructed 3D face.

The significance of the 3D model fitting technique is that a face in a familiar view angle can be rendered by fitting the model to face in any arbitrary view, which is definitely helpful to human face recognition. In this case, the target image (12) shown in Figure 2 could be modelled and the view of the face could be changed to be a direct 'front on' view, rather than a face looking to the left.

The initial work on 3D morphable model is described in *V. Blanz and T. Vetter. A morphable model for the synthesis of 3D faces. In Proceedings of SIGGRAPH, 1999.* The morphable model is a statistical face model which consists of a PCA model of face shape and a PCA model of face texture map. In the work of Blanz and Vetter the morphable model is trained on 3D faces after they are captured by laser scanner Cyberware and registered with a method based on optical flow.

It is wide acknowledged in the psychology field that a caricatured face results in a better recognition result than the veridical face. This is described in, *G. Rhodes.*

Superportraits: Caricatures and Recognition. East Sussex:UK Psychology Press, 1996; P Sinha, B, Balas, Y. Ostrovsky, and R. Russell. Face recognition by humans: Nineteen results all computer vision researchers should know about. Proceedings of the IEEE, 94(11): 1948-1962, 11 2006, and *Alice J O'Toole. Psychological and neural perspectives of human face recognition. In Stan Li and Anil K. Jain, editors, Handbook of face recognition. Springer, 2004.*

Although the caricatured face is a distorted version of the veridical face, distinctive facial features are emphasised in the caricatured face. *G. Byatt and G. Rhodes, "Recognition of own-race and other-race caricatures: implications for models of face recognition". Vision Research, 38:2455-2468, 1998* explains the reason why a caricatured face is more recognisable, based on two different models of face coding in psychological face space. In the norm-base coding model, the face is encoded with respect to the mean face, therefore the distinctiveness of a specific face is determined by the distance between mean face and the specific face. That is why the caricatured face is more distinctive than the veridical face. In the absolute-coding model, the distinctiveness of a face is determined by the local density of the face samples in its neighbourhood. The caricatured face located in a region with lower density than the veridical face, therefore it is more distinctive.

A. J. O'Toole, T. Vetter, and V. Blanz, "Three-dimensional shape and two-dimensional surface reflectance contributions to face recognition: an application of three-dimensional morphing". Vision Research, 39:3145-3155, 1999 describes measuring the contributions of 3D shape and 2D surface reflectance to human face recognition across viewpoints. This work found that both shape and surface reflectance contribute substantially to recognition of male and female faces, however, shape contains more discriminative information for male faces than female faces. It has also been found that 3D shape caricaturing increased the apparent age of the face, this is described in more detail in *A. J. O'Toole, T. Price, T. Vetter, J. C. Barlett, and V. Blanz, "3D shape and 2D surface textures of human face: the role of "averages" in attractiveness and age". Image and Vision computing, 18:9-19, 1999.*

D. A. Leopold, A. J. O'Toole, T. Vette, and V. Blanz. "Prototype-referenced shape encoding revealed by high-level after-effects". Nature Neuroscience, 4(1):89-94, 2001 is a paper that is concerned with the after effect of identity perception. In this work, the line connecting the average face and an individual's face is termed the 'face identity trajectory'. Along this face identity trajectory, the anti-face has negative identity strength, and the identity strength of the average face is zero. The identity strength increases during anti-caricaturing and reaches 1 at the original face. It is found that the exposure to an individual face for a few seconds will affect the subsequent perception of face identity. As described in *Leopold et al* displaying morphing along the identity trajectory will facilitate the recognition of a test face on the identity trajectory and impair the recognition of faces belonging to other identities.

A flow diagram of a proposed 3D face morphing system is shown in Figure 5. The system typically includes images capture means such as a camera (not shown), and image processing means (not shown), which is generally a computer system. The face morphing system takes a 2D face image (80) of a subject to be recognised as an input image and reconstructs a corresponding 3D face of the recognised and reconstructs a corresponding 3D face by fitting (82) a generic 3D morphable model (84) to the 2D face image.

The 2D face image (80) of the subject' face is typically obtained using the image capture means. The 2D image is then processed by the image processing means to generate image data (for example, pixel intensity) which can undergo further processing. The initial processing of the 2D image to generate the image data may take place in the camera or in the associated computer system. The subsequent processing steps will generally take place in the computer system, which has been appropriately programmed to perform the processing steps.

The image data generated from the 2D face image obtained by the camera represents a morphable image (86) of the subject's face. The subsequent processing of the image data will morph the morphable image (86) to produce a morphed image (96) of the subject's face.

In a preferred embodiment, data representing a generic 3D morphable model (84) is fitted to the image data representing the 2D face image (80) to produce image data representing a 3D morphable face (86). The image data representing the 3D morphable face (86) can be subsequently processed to ultimately generate a final morphed image (96) of the subject's face. Several different ways of processing this image data can be performed, each way is equivalent to morphing the 3D morphable face (86) in an alternative way. The particular processing performed on the image data representing the 3D morphable face (equivalent to a particular type of morphing) is generally based on the choice of the operator of the 3D face morphing system. Four different types of morphing are shown in Figure 5. These are 3D caricaturing (88), morphing on a defined direction (90), multiple channel morphing (92) and model based morphing (94), all of which have been described above. The result of the morphing is a morphed face image (96). The resultant morphed image (96) is then easier for another human to identify. All of these steps can be performed on a standard computer system loaded with appropriate software for performing the various steps required.

As mentioned earlier Blanz and Vetter did early work in the field of 3D morphable models. Their paper *"A morphable model for the synthesis of 3D faces". In Proceedings of SIGGRAPH, 1999* describes a generic 3D morphable model that creates texture by assigning an RGB colour value to each vertex of the 3D mesh, which is then used to interpolate colour values across the surface of each polygon.

J. R. Tena, R. S. Smith, M. Hamouz, J. Kittler, A. Hilton, and J. Illingworth. 2D face pose normalisation using a 3D morphable model. In Proc. Of International Conference on Video and Signal Based Surveillance (AVSS 07), pages 1-6, September 2007 describes another method to register a set of 3D training faces to produce a generic 3D morphable model. The resultant generic 3D morphable model can then be used as the 3D morphable model of Figure 5 described above, to be fitted to the image data of the 2D image. *Tena et al* presents an evaluation of a deformable surface method as described in *Mao et al "Constructing dense correspondences to analyze 3D facial change" Proc. 17th Int. Conf. Path. Recognition (IKPR 04) page 144-148, Aug 2004*, for estimating dense correspondence by conforming a generic model to a layer data set. The evaluation was performed on a data set of 912 training images. In the 3D face morphing system of Figure 5 described above, the model of *Mao et al* has been modified by the Inventors in the following ways:

i) the use of an adaptive search radius during the local matching stage,

ii) an iterative coarse to fine approach, and

iii) enforcing symmetry to aid the matching stage.

These modifications lead to an improvement in mean error and rms of the resultant generic 3D morphable model when compared to the model generated by the standard approach of *Mao et al.*

The original 3D faces (the training images) used to generate the generic 3D morphable model were captured by 3DMD scanner (http://www.3dmd.com/.)

In contrast, to the method described in Blanz and Vetter, the 3D face morphing system described with reference to figure 5 uses a texture map warped to the 3D shape model. This allows texture detail of the face to be preserved, despite using a 3D shape model of only 6000 polygons.

More details regarding the generic 3D morphable model used in the system of figure 5 can be found in *J. R. Tena, R. S. Smith, M. Hamouz, J. Kittler, A. Hilton, and J. Illingworth. 2D face pose normalisation using a 3D morphable model. In Proc. Of Inernational Conference on Video and Signal Based Surveillance (AVSS 07), pages 1-6, September 2007.* The model fitting approach described in this citation is similar to that proposed in *Blanz and Vetter* (referenced above), However, unlike *Blanz and Vetter*, the algorithm of *Tena et al* is adapted to handle texture maps, rather than interpolating the colour at each polygon's centroid by averaging the RGB values of its vertices, as is done in *Blanz and Vetter.* The RGB values of all the pixels in the texture map that are warped to the polygon are averaged.

As mentioned earlier, the 3D morphable model can be represented by projection coefficients. To fit the resultant generic 3D morphable model to a face image that has been obtained under unknown pose and illumination conditions, an optimisation process is needed to tune the shape coefficients and texture coefficients along with rendering parameters to minimise the difference of the input image and the rendered image based on those optimised shape and texture coefficients. The rendering parameters include pose angles, 3D translation, ambient light intensities, directed light intensities and angles, and other parameters of the camera and colour channels. The well known illumination model of Phong (B. T. Phong, "Illumination for Computer Generated Pictures" Comm ACM Vol 18(6) p. 311 – 317 June 1975) is adopted in the rendering process to describe the diffuse and specular reflection of the surface.

The various functionalities of the 3D face morphing system described herein with reference to figure 5 include 3D model fitting, 3D caricaturing, multiple channel morphing, model based morphing, and morphing on a user-defined direction. These morphing processes are all performed on the 3D morphable image produced as a result of fitting the generic 3D morphable model to the image data representing the 2D image of the subject's face. Each of these different morphing processes uses the specific techniques described earlier in the description and are now described in turn below.

1. *Fitting a 3D model to a 2D face:*

Figure 6 shows a 3D face reconstructed from a 2D image (100) using a morphable model (84). The 2D image (100) on the left hand side of the figure is the original 2D facial image of the subject to be recognised. This is fitted (82) (by morphing) to a generic 3D morphable face model (84). Image data representing the 2D image is obtained as described above with reference to Figure 5. The obtained data is then processed by fitting data (82) representing the 3D morphable face (84) to the image data of the 2D image. This model fitting stage will result in the generation of a 3D morphable face. The right hand side of the figure shows example 2D images (96A, 96B, 96C) of the resultant 3D face from various different directions. Using the resultant 3D face, the original subject face to be recognised (100) can be rendered in various different, arbitrary poses. For example, the subject's face can be rendered to appear 'front on', instead of slightly posed to the right hand side (as you look at the original image (21)). A 'front on' image is generally easier for a human to recognise than an image that is not 'front on'.

2. *3D caricaturing:*

3D caricaturing is implemented as a morphing along the line connecting the average 3D face obtained from a set of training images and the given face to be recognised. The whole process is illustrated in Figure 3 as described earlier. All the faces in Figure 3 are shown with a 30 degree pose. Of course, other face poses may result from the caricaturing process, and the faces may be shown 'face on', or with an alternative pose, or with a specific tilt upwards or downwards of the head. The real 3D face (30) of Figure 3 is obtained from a 2D image of the subject's face by processing image data with a generic 3D morphable model as described previously. Image data representing the resultant 3D face (30) is then processed according to the caricature process described earlier.

In the system used here, the facial features to be caricatured are selected by the operator who will use their judgement in view of the overall impression created by the subject's face. For example, the operator may decide to create a caricature by changing (increasing/reducing) the size of a facial feature, or by changing the intensity of the colour of a facial feature (e.g. heighten facial redness, or increase the intensity of eye colour). Other type of caricature (not specifically described) may also be performed.

The operator can also instruct the system to perform a series of caricatures, rather than being limited to just changing one facial feature. For example, the operator may decide that they wish to increase the size of the subject's nose, then to reduce the size of the subject's ears, then to make the chin more pronounced, and so on.

3. *Morphing on multiple channels:*

The option of processing the image data of the 3D morphable face to morph the 3D face on a shape channel and/or a texture channel is also provided by this system. Figure 7 illustrates the change in a subject's face as the image data is processed so that the 3D morphable face is morphed along the shape and texture channel from a male face (110) to a female face (112). This figure shows 6 different intermediate faces (110A, 110B ....) as the 3D morphable face is morphed from male to female, but there may be any number of intermediate faces between the male (110) and female faces (112). It is clear from figure 6 that the overall face shape has changed as the face changes from male to female and also that the appearance (texture) of various facial features has changes, for example the chin is less square in the female, and the females eyebrows are less pronounced. Other facial features (not specifically described) have also changed.

Figure 8 also illustrates the change in a face as it is morphed along the shape channel only from a male face (114) to a female face (116). Again, the morphing arises as a result of processing the image data of the 3D morphable face. No changes occur on the texture channel, this means only that shape of the face is changed, there are no changes to the texture of the face. Like Figure 7 this Figure shows six different intermediate faces (114A, 114B.....) in the change from male (114) to female (116), but again there may be any number of intermediate faces (114A ....114N) between the starting male face (114) and the final female face (116).

Figure 9 illustrates the change in a face as it is morphed along the texture channel only from a male face (118) to a female face (120). Again, the morphing arises as a result of processing the image data of the 3D morphable face to morph the 3D morphable face. In this embodiment no facial changes occur on the shape channel and so the shape of the face is unchanged. As for Figures 7 and 8 there may be any number of intermediate faces (118A ....118N) between the starting face (118) and the final face (120).

In all the examples of Figures 7, 8 and 9 the starting face (110, 114, 118) is male and the end face is female (112, 116, 120). Alternatively the starting face may be female and be transformed by processing the image data and morphing to a male face (again with any number of intermediate faces), or the gender of the starting face (male/female) may be unchanged by the morphing process as the image data is processed and morphing on shape and/or texture channels may simply change the appearance of the face but not the gender of the subject. Also, in all of the figures, all of the images in the morphing process are shown in frontal view. Alternatively the faces may be shown within a particular pose (non-frontal view) and/or with a particular tilt of the face.

4. *Model based morphing:*

If the 3D morphable face is projected to the morphable model space, then the image data can be processed in such a way that morphing can be carried out on the model coefficients, and the desired faces can be reconstructed from the resulting projection coefficients after the processing has been completed. The result will generally exhibit no difference from processing image data of the 3D faces directly, rather than processing of the projection coefficients of the image data. However, the morphable model offers another type of morphing, which is realised by varying local projection coefficients of the image data of the morphable model. Figure 10 illustrates the change in an average face (122) resulting from model based morphing by varying a first coefficient of the image data of the shape model, but leaving the coefficients of the image data texture model unchanged. The face after the processing of the coefficients is at the right hand side (124). In the example shown, the gender of the subject has not changed (Figure 10 shows an average male face, but the processing of the image data and subsequently the morphing could apply to a female face), but this technique can be applied to change the gender from male to female and vice versa. Of course, the model based morphing could also be used to vary coefficients of the texture model, whilst leaving the shape model unchanged, or may vary coefficients of both the shape and texture model together. It seems that this first coefficient of the shape controls the ratio model of the size of the upper face to that of the lower part. Also there may be any number of intermediate faces (122A....122N) between the initial face (122) and the final face (124).

5. *Morphing along defined directions:*

Another function provided by the system is processing the image data so that the 3D morphable face is morphed along a direction defined by two faces (126, 128) selected by the user. An example of processing the image data to morph the average face in the texture channel along the direction defined by two female faces with different skin colour is shown in Figure 11. The morphing induces a transform of skin colour from one subject (130) to the other (132). The starting average female face (130) is European, and the final face (132) is an Afro-Carribean face. The face passes through intermediate faces (130A, 130B.....) as the morphing proceeds along the defined direction. The morphing may be along a texture channel and/or along a shape channel of the defined direction. The morphing generally will change one or more race specific characteristics of the morphable image, for example, the characteristic may be skin colour, hair colour, hair texture, facial feature size and facial feature orientation. In the example of Figure 11 the gender of the face is not changed, but the morphing process may be such as to change the gender of the starting subject, as well as changing at least one race specific characteristic. Alternatively, the race of the two faces defining the direction may be different, e.g. European, African, Indian Asian, Chinese Asian. In some case, the skin colour may not change but other race characteristics will change. Typically, the reference images that define the morphing direction will be pre-set. In an embodiment of the invention, the system may include various pre-defined directions related to race or gender morphing, for example. In this case, the operator will select the particular morphing operation to be performed on the image of the subject's face and the relevant reference images defining the necessary direction will be selected from a central database.

This will allow the morphing to be performed relatively quickly. Alternatively, the operator may decide to manually review the images in the central database and to select particular reference images to define the morphing direction for a particular morphing operation to be carried out.

Figure 5 as described above, shows a two stage morphing system. That is, a model fitting stage (82) to produce a 3D morphable face (86), followed by four alternative methods (88, 90, 92, 94) of morphing the resultant morphable 3D face. The various morphing methods have all be described above.

Of course, it is entirely possible, from a 3D face model (80) that has been morphed by one of the four morphing processes (88, 90, 92, 94) to undergo one or more further morphing steps. The subsequent morphing steps may be carried out by performing any of the four types of morphing process. It does not have to be the same as the morphing process initially performed, although the same morphing techniques may be used.

For example, the image data could be morphed on multiple channels (shape/texture) to change the gender of the subject, and the resultant morphed image may be morphed again on multiple channels to change a particular facial shape/texture characteristic.

Alternatively, the image data could be morphed on multiple channels to change the gender of the subject, and the resultant morphed image may be morphed again, by a 3D caricature process, to change the size of a particular facial feature, for example.

The resultant morphed image from a multiple (2 stage) morphing process may then be present to the operator for recognition or they may undergo yet more morphing.

Once the morphed image of the subject's face has been generated it can be compared to one or more images from a pre-existing set of gallery images of target faces. Typically, the gallery images are stored on the computer system, and a subset of gallery images with facial features similar to the subject can be called up.

For example, if the subject is a white male, age 30 – 40, with short blonde hair and blue eyes then the gallery images selected from comparison will also have all of these specific features. The gallery is generally provided with enough gallery images to produce subset of gallery images for all races, ages, gender and other facial characteristics.

The subset of gallery images can be selected manually by the operator after review of the entire gallery, or automatically by the system, once various parameters (race, hair colour, age, gender, etc....) have been entered by the system operator to define the facial features of the subject. However, the subset of gallery images is selected they are then displayed, on a computer screen for example, for the human operator to review.

The human operator will look at the morphed image of the subject, and compare the image with the selected gallery images and then decide which of the gallery images corresponds to an image of the subject. Of course, the various different morphing processes described herein can also be applied to the gallery images.

In one embodiment of the invention, one or more of the gallery images can be morphed to produce morphed gallery images. The morphed gallery images can be compared with an unmorphed directly obtained image of the subject, to assist in recognition of the subject by a human operator.

In an alternative embodiment of the invention, the image of the subject's face is morphed as described previously, and one or more of the gallery images can also be morphed. Typically, although not always all of the images (the subject image and the selected gallery images) will undergo the same type of morphing in the same sequence e.g. change of gender, then change of race, then caricature of a particular facial feature. However, it may be that the subject's face undergoes one or more morphing steps e.g. change of race, then change of gender, then change of eye colour, whereas the gallery images undergo more or less morphing steps e.g. only the race of the gallery image is changed, and vice versa.

The resultant morphed image of the subject, and morphed gallery images can then be presented, on a computer screen for example, to the human operator to assist recognition of the subject's face by the operator.

Typically, in the embodiment described above, the faces represented by each of the gallery images will undergo the same model based morphing as the image of the subject's face. This will make it easier for the operator to identify the subject's face as one of the faces presented in the gallery images.

Also, it is generally easier for a morphed face to be recognised if the race of the image of the subject's face is morphed to be the same as the race of the operator who is required to identify the image of the subject.

CLAIMS

1. A method for recognition of a subject's face comprising the steps of:

producing image data representing a morphable image of the subject's face;

processing said image data to produce a morphed image of the subject's face;

and presenting said morphed image for recognition.

2. A method according to claim 1 wherein said image data represents a 3D morphable image of the subject's face.

3. A method according to claim 2 wherein the step of producing said image data includes the steps of obtaining a 2D image of the subject's face and generating a 3D morphable image from said 2D image.

4. A method according to claim 3 wherein said image data is produced by fitting a 3D morphable model to said 2D image.

5. A method according to claim 4 wherein said 3D morphable model is a Principal Component Analysis (PCA) model of face shape and/or face texture.

6. A method according to any one of claims 1 to 5 wherein said image data is processed by a 3D caricature process.

7. A method according to claim 6 wherein said 3D caricature process is a linear morphing process defined by

$$M = S + \lambda \ (D - S)$$

where M represents the resultant morphed image, D represents the subject's face, S represents an average facial image from a set of reference images and λ is a morphing coefficient.

8. A method according to claim 6 wherein said 3D caricature process is a linear morphing process defined by:

$$M = D + \lambda (S1 - S2)$$

where M represents the resultant morphed image, D represents the subject's face, S1 and S2 represent a first and second reference images from a set of reference images and λ is a morphing coefficient.

9. A method according to claim 8 where S1 and S2 represent average faces of different gender, or different races, different ages or other identifiable coherts.

10. A method according to any of claims 7 to 9 where $\lambda > 1$.

11. A method according to any one of claim 1 to 5 wherein said image data is processed by model based fitting said image data with a target face model, where said target face model comprises a statistical shape model and/or a statistical texture model.

12. A method according to claim 11 wherein said statistical shape model and/or said statistical texture model includes one or more target projection coefficients and said image data includes one or more source projection coefficients, said projection coefficients including one or more of face size, face width, face length, head tilt parameters, relative width of facial subsection and skin colour.

13. A method according to claim 12 wherein said image data is projected onto a subspace spanned by at least one of said statistical shape model and said statistical texture model and said image data is represented by one or more of said source projection coefficients.

14. A method according to claim 13 wherein said image data is processed by interpolating said source projection coefficients with the corresponding target projection coefficients of said statistical shape model and/or said statistical texture model.

15. A method according to any of claims 11 to 14 wherein said target face model is a 3D face model.

16. A method according to any of claims 13 to 15 wherein said subspace is a Principal Component Analysis (PCA) subspace.

17. A method according to any one of claims 14 to 16 wherein at least one of said target projection coefficients is varied before said interpolation of said target

and source projection coefficients is performed, thereby changing at least one facial characteristic to which the varied target projection coefficient relates, in the resulting morphed image.

18. A method according to any of claims 1 to 5 wherein said image data is processed by morphing along a direction defined by two different facial reference images.

19. A method according to claim 18 wherein said morphing along a direction processes the image data along a texture channel and/or a shape channel of the defined direction.

20. A method according to claim 19 wherein processing the image data changes a race specific characteristic of the image data.

21. A method according to claim 20 wherein the race specific characteristic is one of skin colour, hair colour and/or texture, size and/or orientation of various facial features.

22. A method according to any of claims 19 to 21 wherein processing the image data changes the gender of the morphable image.

23. A method according to any of claims 2 to 22 wherein said 2D image is obtained by a camera.

24. A method according to any of claims 6 to 23 wherein said image data is processed to produce said morphed image by performing a plurality of processing steps, each intermediate processing step producing intermediate image data and said final processing step producing said morphed image.

25. A method according to claim 24 wherein said plurality of processing steps are all performed using the same processing technique.

26. A method according to claim 24 wherein said plurality of processing steps are not all performed using the same processing technique.

27. A method according to any of claims 2 to 26 further comprising the steps of:

providing a set of gallery images of one or more target faces;

processing image data representing said gallery images to produce morphed gallery images of said target faces;

presenting said morphed gallery images along with said morphed image of said subject's face for comparison of said morphed gallery images with said morphed image.

28. A method according to claim 27 wherein said gallery image data is processed in the same way as said image data representing said subject's face is processed.

29. A method according to claim 27 wherein said gallery image data is processed in a different way to the way said image data representing said subject's face is processed.

30. A facial image processing system for presenting an image of a subject's face for recognition of said subject comprising.

acquisition means for acquiring image data representing a morphable image of the subjects face;

processing means for processing said image data to produce a morphed image of the subject's face;

presentation means for presenting said morphed image for recognition of said subject.

31. An image processing system according to claim 30 wherein said image data represents a 3D morphable image of the subject's face.

32. An image processing system according to claim 31 wherein said acquisition means acquires image data by obtaining a 2D image of the subject's face and generating a 3D morphable image from said 2D image.

33. An image processing system according to claim 32 wherein said processing means processes said image data by fitting a 3D morphable model to said 2D image.

34. An image processing system according to any of claims 30 or 33 wherein said processing means processes said image data by a 3D caricature process.

35. An image processing system according to claim 34 wherein said 3D caricature process is a linear morphing process defined by

$$M = S + \lambda (D - S)$$

where M represents the morphed image, D represents the subject's face, S represents an average facial image from a set of reference images and λ is a morphing coefficient.

36. An image processing system according to claim 34 wherein said 3D caricature process is a linear morphing process defined by

$$M = D + \lambda (S1 - S2)$$

where M represents the resultant morphed image, D represents the subject's face, S1 and S2 represent first and second reference images from a set of reference images and λ is a morphing coefficient.

37. An image processing system according to any of claims 30 or 33 wherein said processing means processes said image data by model-based fitting said image data with a target face model, where said target face model comprises a statistical shape model and /or a statistical texture model.

38. An image processing system according to claim 37 wherein said statistical shape model and/or said statistical texture model include one or more target projection coefficients and said image data includes one or more source projection

coefficients, said projection coefficients including one or more of face size, face width, face length, head tilt parameters, relative width of facial subsections and skin colour.

39. An image processing system according to claim 38 wherein said processing means projects said image data into a subspace spanned by at least one of said statistical shape model and said statistical texture model and represents said image data by one or more of said source projection coefficients.

40. An image processing system according to claim 39 wherein said processing means processes said image data by interpolating said source projection coefficients with the corresponding target projection coefficients of said statistical shape model and/or said statistical texture model.

41. An image processing system according to claim 40 wherein said processing means varies at least one of said target projection coefficients before said interpolation of said target and source projection coefficients, thereby changing at least one facial characteristic to which the varied target projection coefficient relates in the resulting morphed image.

42. An image processing system according to any of claims 30 or 33 wherein said processing means processes said by image data by morphing along a direction defined by two different facial reference images.

43. An image processing system according to claim 42 wherein said processing means processes said image data along a texture channel and/or a shape channel of said defined direction.

44. An image processing system according to claim 43 wherein said processing means processes said image data along a texture channel to change a race specific characteristic of said image data.

45. An image processing system according to claim 43 or 44 wherein said processing means processes said image data to change the gender of said morphable image.

46. An image processing system according to any of claims 30 to 45 wherein said acquisition means includes a camera for obtaining said 2D image.

47. An image processing system according to any of claims 30 to 46 wherein said processing means processes said image data by performing a plurality of processing steps, each intermediate processing step producing intermediate image data and said final processing step producing said morphed image.

48. An image processing system according to claim 47 wherein said plurality of processing steps are all performed by said processing means using the same processing technique.

49. An image processing system according to claim 47 wherein said plurality of processing steps are not all performed by said processing means using the same processing technique.

50. An image processing system according to any of claims 30 to 49 further comprising;

storage means for storing a set of gallery images of one or more target faces;

wherein said processing means processes image data representing said gallery images to produce morphed gallery images of said target faces, and said presentation means presents said morphed gallery images along with said morphed image of said subject's face for comparison of said morphed gallery images with said morphed image.

51. An image processing system according to claim 50 wherein said processing means processes said gallery image data in the same way as the image data representing the subject's face is processed.

52. An image processing system according to claim 50 wherein said image processing means processes said gallery image data in a different way to the way it processes image data representing said subject's face.

53. An image processing system according to any one of claims 30 to 46 wherein said presentation means is a computer display screen.

54. A computer program product for use in facial recognition of a subject's face comprising;

machine readable media having recorded thereon programming instructions for causing a computer system to:

acquire image data representing a morphable image of the subject's face;

process said image data to produce a morphed image of the subject's face; and

present said morphed image for recognition.

55. A computer program product according to claim 54 wherein said image data represents a 3D morphable image of the subject's face.

56. A computer program product according to claim 55 wherein said instructions for acquiring said image data include instructions to obtain a 2D image of the subject's face and for generating a 3D morphable image from said 2D image.

57. A computer program product according to claim 54 wherein said image data is processing by fitting a 3D morphable model to said 2D image.

58. A computer program product according to claim 57 wherein said 3D morphable model is produced by a Principal Component Analysis (PCA) model of face shape and/or face texture.

59. A computer program product according to any one of claims 54 to 58 wherein said image data is processed by a 3D caricature process.

60. A computer program product according to claim 59 wherein said 3D caricature process is a linear morphing process defined by

$$M = S + \lambda\ (D - S)$$

where M represents the resultant morphed image, D represents the subject's face, S represents an average facial image from a set of reference images and λ is a morphing coefficient.

61. A computer program product according to claim 59 wherein said 3D caricature process is a linear morphing process defined by.

$$M = D + \lambda\,(S1 - S2)$$

where M represents the resultant morphed image, D represents the subject's face, S1 and S2 represent a first and second reference images from a set of reference images and λ is a morphing coefficient.

62. A computer program product according to claim 61 where S1 and S2 are average faces of different gender, difference race, different age or other identifiable cohorts.

63. A computer program product according to any of claims 60 to 62 where $\lambda > 1$.

64. A computer program product according to any one of claim 56 to 58 wherein said image data is processed by model based morphing said image data with a target face model, where said target face model comprises a statistical shape model and/or a statistical texture model.

65. A computer program product according to claim 64 wherein said statistical shape model and/or said statistical texture model includes one or more target projection coefficients and said image data includes one or more source projection coefficients, said projection coefficients including one or more of face size, face width, face length, head tilt parameters, relative width of facial subsection and skin colour.

66. A computer program product according to claim 65 wherein said image data is projected onto a subspace spanned by at least one of said statistical shape model and said statistical texture model and said image is represented by one or more of said source projection coefficients.

67. A computer program product according to claim 66 wherein said image data is processed by interpolating said source projection coefficients with the corresponding target projection coefficients of said statistical shape model and/or said statistical texture model.

68. A computer program product according to any of claims 64 to 66 wherein said target face model is a 3D face model.

69. A computer program product according to any of claims 56 to 68 wherein said subspace is a Principal Component Analysis (PCA) subspace.

70. A computer program product according to any one of claims 67 to 69 wherein at least one of said target projection coefficients is varied before said interpolation of said target and source projection coefficients is performed, thereby changing at least one facial characteristic to which the varied target projection coefficient relates, in the resulting morphed image.

71. A computer program product according to any of claims 54 to 58 wherein said image data is processed by morphing along a direction defined by two different facial reference images.

72. A computer program product according to claim 71 wherein said morphing along a direction processes the image data along a texture channel and/or a shape channel of the defined direction.

73. A computer program product according to claim 72 wherein processing the image data along a texture channel changes a race specific characteristic of the morphable image.

74. A computer program product according to claim 73 wherein the race specific characteristic is one of skin colour, hair colour and/or texture, size and/or orientation of various facial features.

75. A computer program product according to any of claims 72 to 74 wherein processing the image data changes the gender of the subject's face.

76. A computer program product according to any of claims 54 to 75 wherein said instruction to acquire image data include instruction to a camera to obtain said 2D image.

77. A computer program product according to any of claims 54 to 76 wherein said instructions to process said image data include instructions to perform a plurality of processing steps, each intermediate processing step producing intermediate image data and said final processing step producing said morphed image.

78. A computer program product according to claim 77 wherein said instructions to perform each of the plurality of processing steps are instructions to use the same processing techniques for each processing step.

79. A computer program product according to claim 77 wherein said instructions to perform each of the plurality of processing steps are such that not all of the processing steps are performed using the same processing techniques.

80. A computer program product according to any one of claims 54 to 79 comprising further programming instructions for causing a computer system to:

access storage means containing a gallery of images of target faces;

process image data representing said gallery images to produce morphed gallery images of said target faces;

presents said morphed gallery images along with said morphed image of said subject's face for comparison of said morphed gallery images with said morphed image.

81. A computer program product according to claim 80 wherein said gallery image data is processed in the same way as said image data representing said subject's face is processed.

82. A computer program product according to claim 80 wherein said gallery image data is processed in a different way to the way said image data representing said subject's face is processed.

83. A method for recognition of a facial image substantially as herein described with reference to Figures 3 to 11 the accompanying drawings.

84. A facial image processing system substantially as herein described with reference to Figures 3 to 11 the accompanying drawings.

85. A computer program product substantially as herein described with reference to Figures 3 to 11 the accompanying drawings.

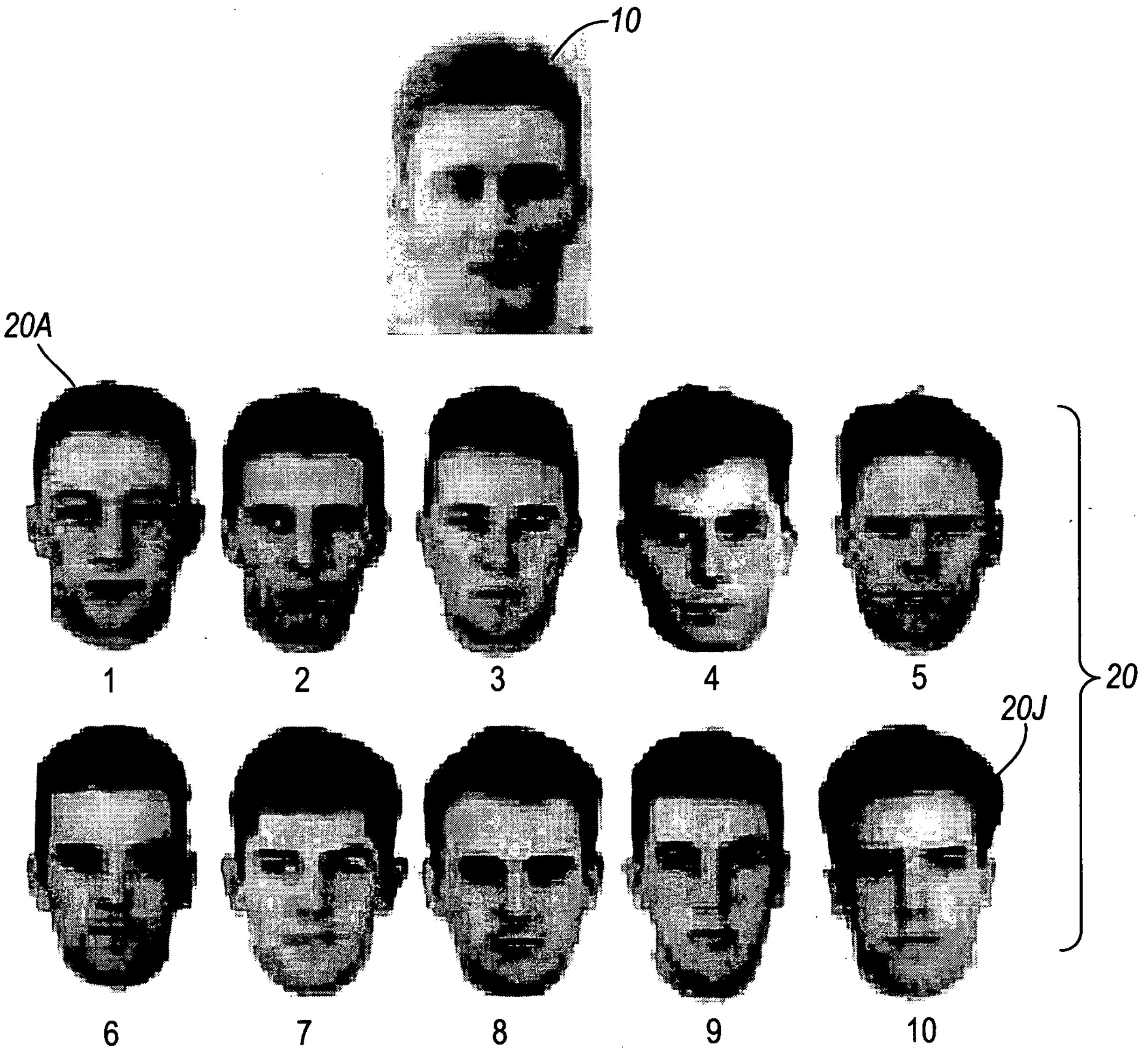

Fig.1

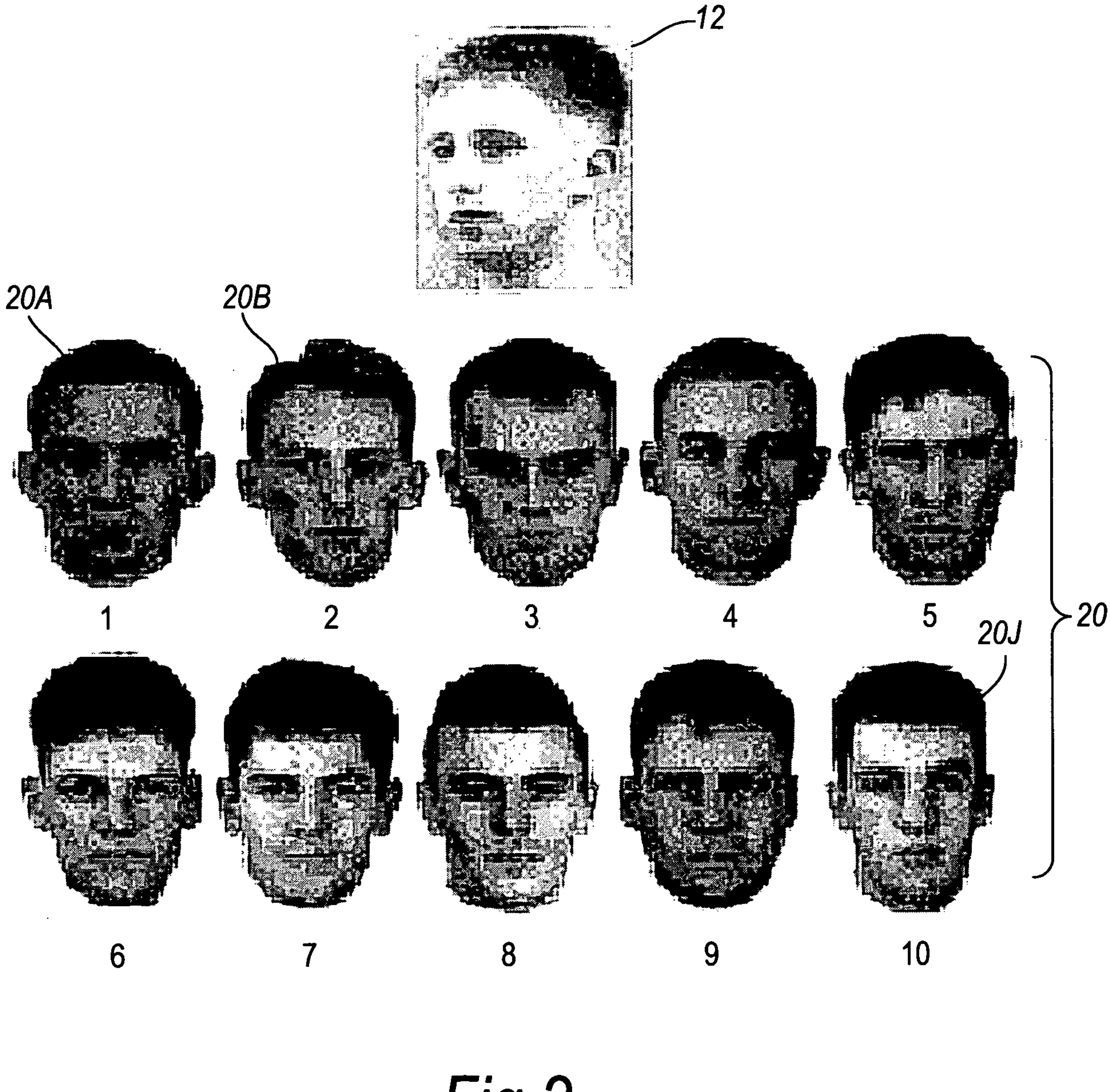

Fig.2

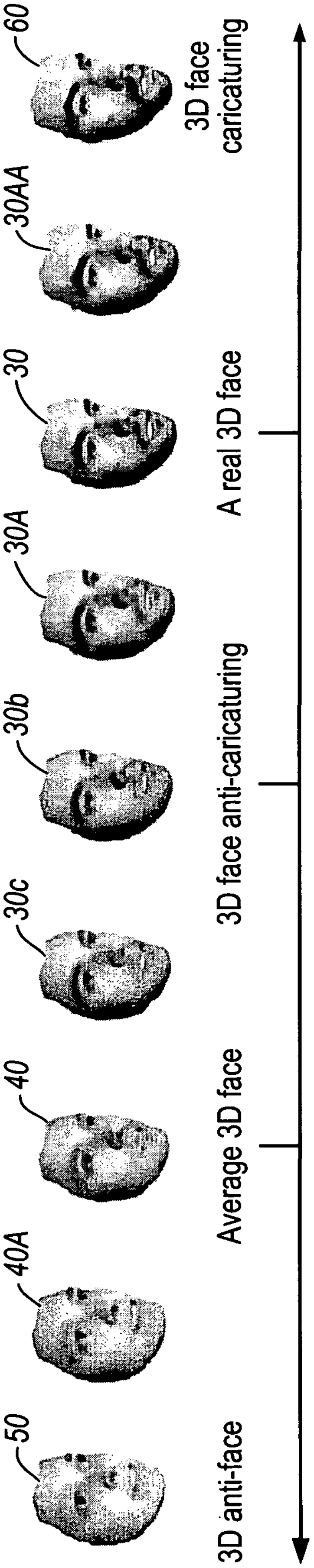
50
3D anti-face
40A
40
Average 3D face
30c
30b
3D face anti-caricaturing
30A
30
A real 3D face
30AA
60
3D face caricaturing

Fig.3

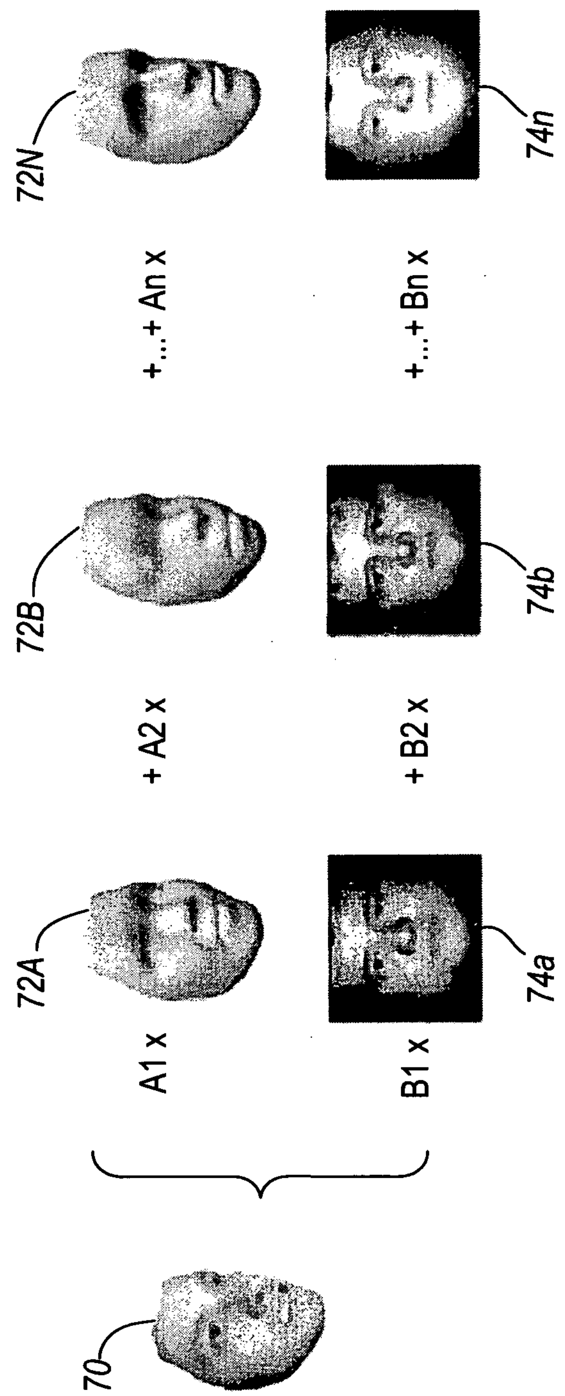
70
A1 x
72A
B1 x
74a
+ A2 x
72B
+ B2 x
74b
+...+ An x
72N
+...+ Bn x
74n

Fig.4

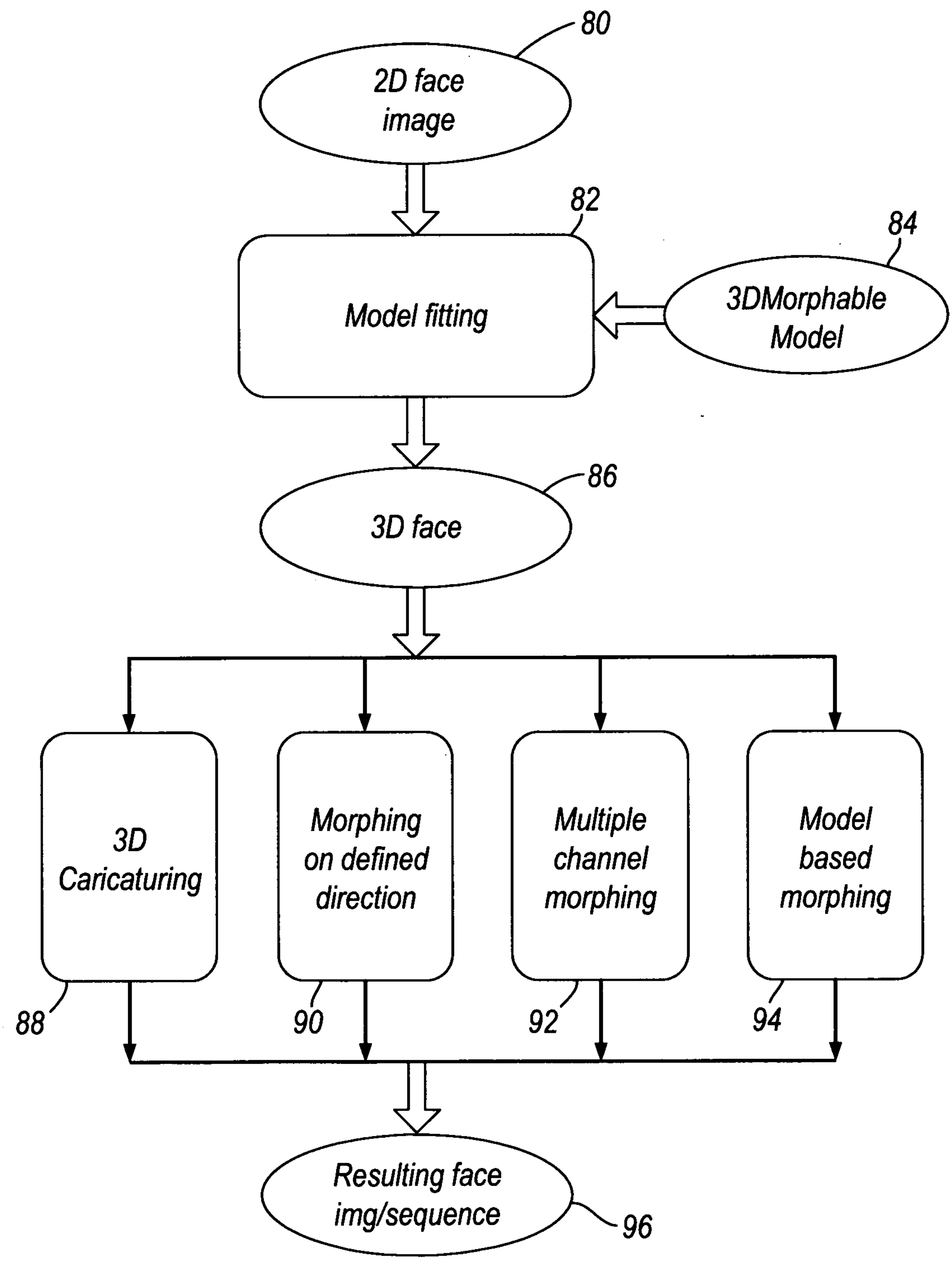
2D face image
80
82
Model fitting
84
3DMorphable Model
3D face
86
3D Caricaturing
Morphing on defined direction
Multiple channel morphing
Model based morphing
88
90
92
94
Resulting face img/sequence
96

Fig.5

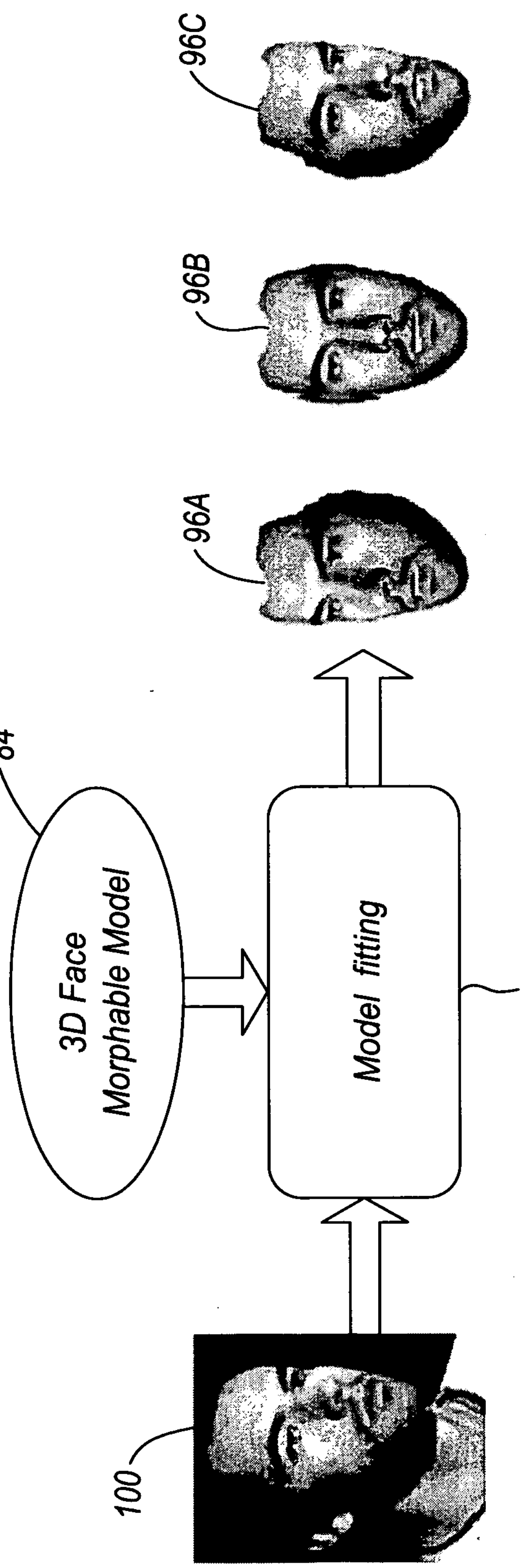

Fig.6

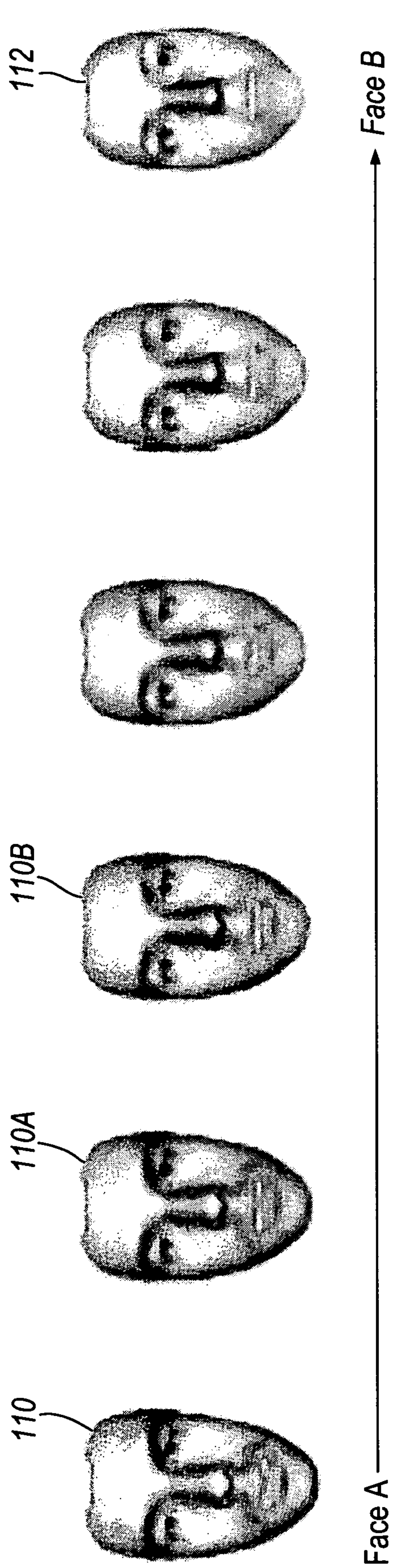

Fig.7

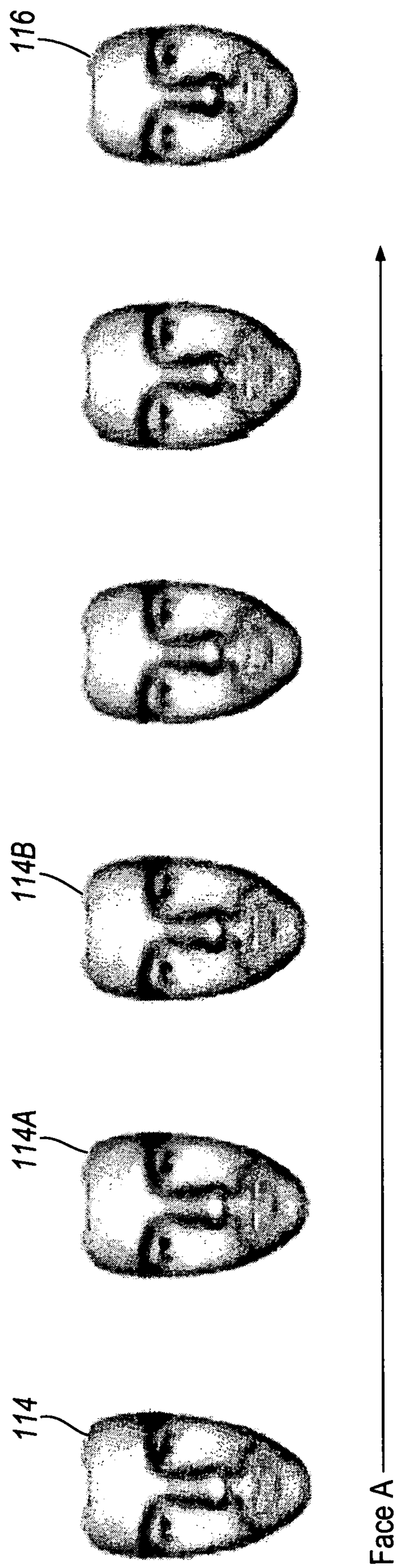

Fig.8

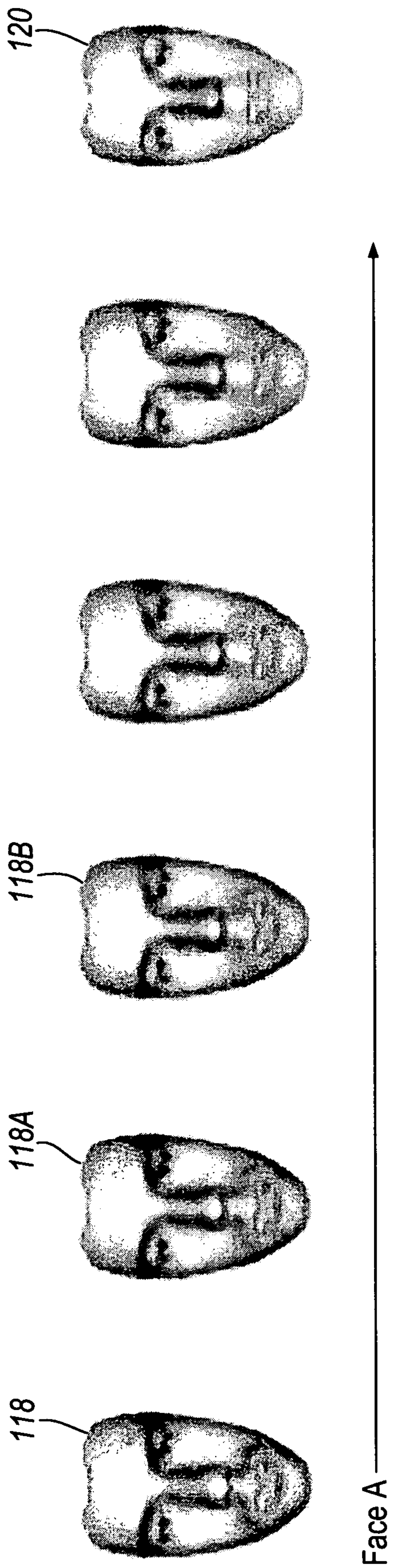

Fig.9

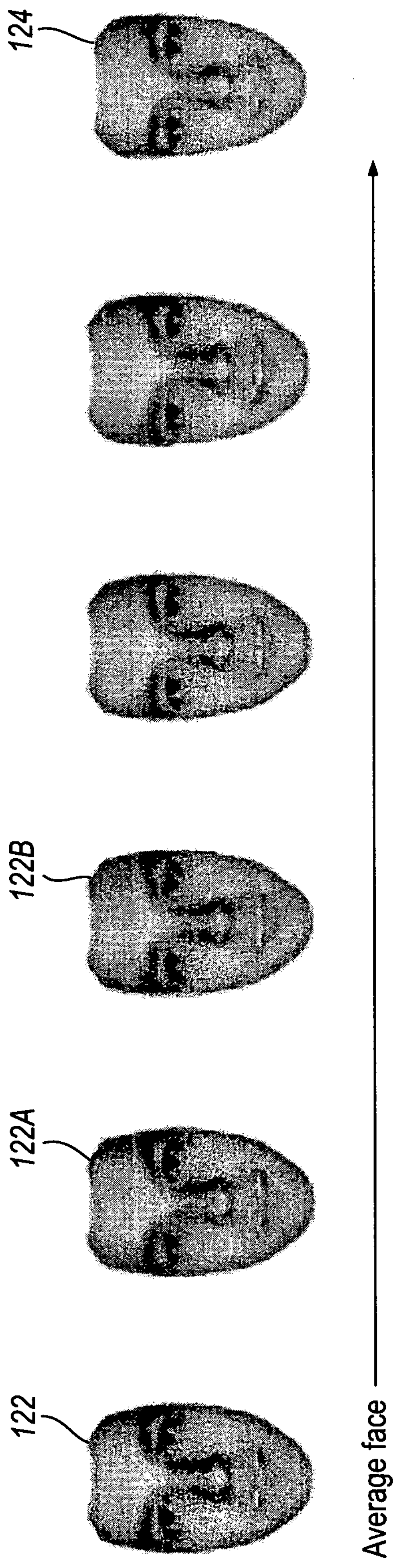

Fig.10

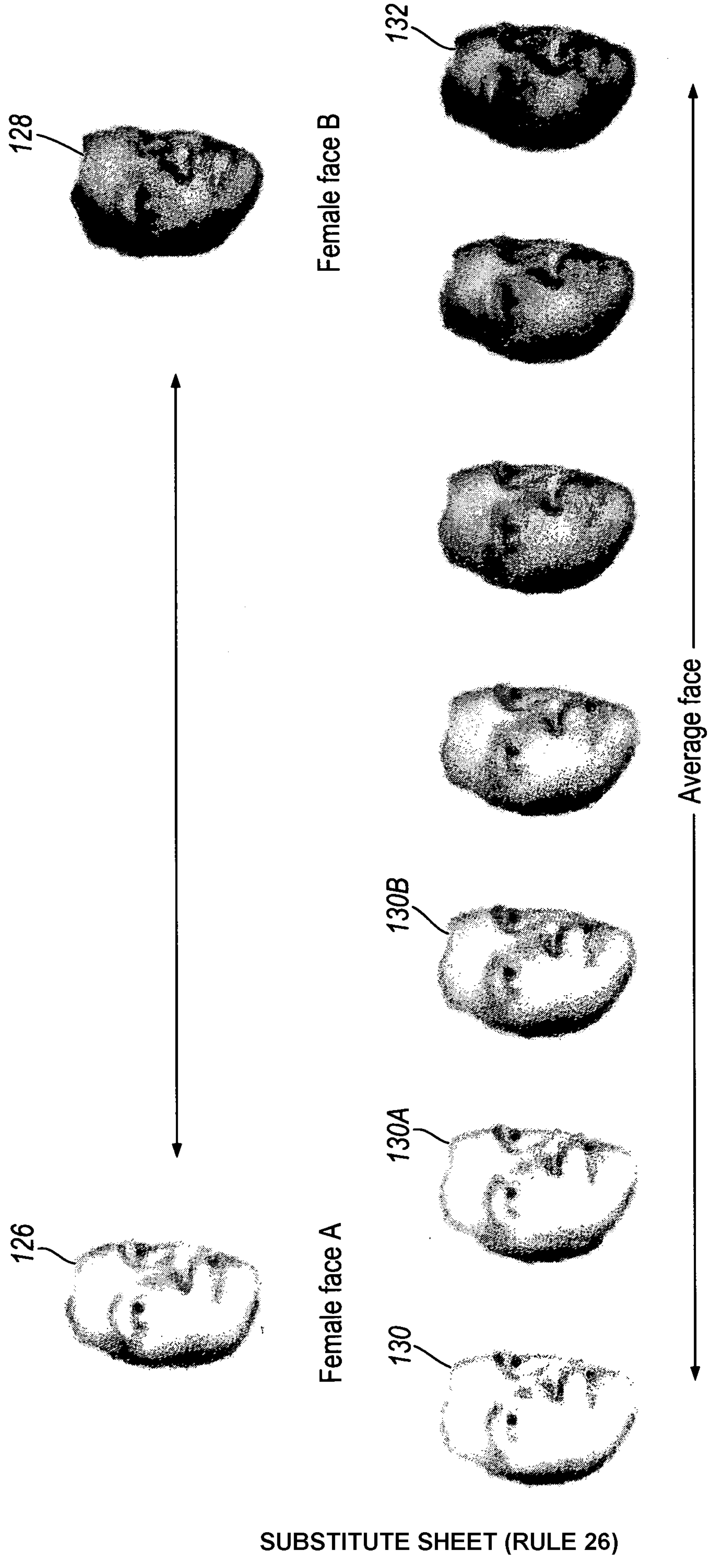
128
Female face B
126
Female face A
132
130B
130A
130
Average face

Fig.11

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2009/001811

A. CLASSIFICATION OF SUBJECT MATTER
INV. G06K9/36

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)
G06K G06T

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 practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	COSTEN N ET AL: "Manifold caricatures: on the psychological consistency of computer face recognition" AUTOMATIC FACE AND GESTURE RECOGNITION, 1996., PROCEEDINGS OF THE SECO ND INTERNATIONAL CONFERENCE ON KILLINGTON, VT, USA 14-16 OCT. 1996, LOS ALAMITOS, CA, USA,IEEE COMPUT. SOC, US, 14 October 1996 (1996-10-14), pages 4-9, XP010200392 ISBN: 978-0-8186-7713-7	1,11-14, 16-30, 37-54, 71-85
Y	the whole document	2-10,15, 31-36, 55-70
Y	EP 1 039 417 A (MAX PLANCK GESELLSCHAFT [DE]) 27 September 2000 (2000-09-27) abstract	2-10,15, 31-36, 55-70

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 October 2009	26/10/2009

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Sonius, Michiel

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/GB2009/001811

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
EP 1039417	A	27-09-2000	DE	69934478 T2	27-09-2007
			US	6556196 B1	29-04-2003