Object Recognition Method

Technical Field

The present invention relates to the field of object recognition in 2-dimensional and 3-dimensional space as may be used as part of an artificial intelligence system.

Background

Associated technologies required for 3-dimensional object recognition have already entered the commercial market, such as 3-dimensional scanners which enable a 3-dimensional object to be scanned and a 3-dimensional digital model to be generated. For example 3-dimensional scanners enable the human face to be scanned for computer games and for the generation of 3-dimensional laser images in crystal.

Some current 3-dimensional object recognition systems rely upon environment-dependant conditions such as the distinct colouring of objects.

Other current 3-dimensional object recognition systems rely upon complete 3-dimensional imaging of an object in order to create a normalised set of data pertaining to the object, for example normalisation methods employing an inferred centre of mass of an object. This method is demonstrated in the paper “A Geometric Approach to 3D object Comparison”, Novotni et al, smi, pp.0167, International Conference on Shape Modelling and Applications, 2001.

Other current 3-dimensional object recognition systems rely upon the extraction of affine invariant surface patches, where these patches are normalised for object recognition. This method is demonstrated in the paper “3D Object Modelling and Recognition Using Affine-Invariant Patches and Multi-View Spatial Constraints”, Rothganger et al, Proceedings of the 2003 IEEE Computer Society Conference on Computer Vision and Pattern Recognition, Vol. 2, 2003, pp. II-272-7. This technology enables both the use of appearance and 3-dimensional structure in object recognition.

It is an object of the present invention to provide a 2D and/or 3D object recognition algorithm which will operate independently of the object position and orientation and the viewpoint position and orientation, operate in a large range of lighting conditions and, operate efficiently. The object recognition method will also operate without the need for artificial colouring to be applied to the objects, does not require an object to be viewed from all angles during either the characterisation or recognition phase, will make use of the appearance in object recognition, and for 3D specific recognition, will make use of the 3-dimensional structure, will operate on objects without planar surfaces or sharp edges to aid identification, and does not require a complete 3D image of the object to be obtained.

It should be realized that the method according to the present invention will reduce in performance where object features (points of interest on the object) cannot be extracted. This can occur in the scenario where an object being recognised has both no distinct areas of high curvature in shape, for example corners, and no distinct areas of high curvature in surface texture. However there are other well known methods to identify object features. Also some “degenerate” objects may look the same regardless of the viewing angle and may still be recognisable regardless of the accuracy and repeatability of the object feature extraction method.

Summary of Invention

The present invention consists of a method for generating data for one or more objects residing in one or more scenes in a space defined by an axis system passing through an origin, comprising the steps of:

1. for each of the objects, deriving a set of N-dimensional object data comprising data points, each data point defined by N-dimensional coordinates, one or more of the data points being feature data points with coordinates corresponding to coordinates of object features;
2. for each of the objects, grouping permutations of the coordinates of feature data points of the set of object data as the coordinates of apexes of one or more object triangles, each object triangle comprising three sides and three apexes and defining a plane;
3. for each of one or more of the sides of each of the object triangles of each of the objects, transforming the coordinates of one or more of the data points of the set of object data into transformed coordinates in a new axis system, where the transformation function is a function of the coordinates of the apexes of the object triangle, thereby forming a set of transformed object data; and
4. for each of the one or more sides of each of the object triangles of each of the objects, generating data relating to the set of transformed object data.

Preferably one or more data points comprise an associated one or more light intensity values.

Preferably one or more feature data points comprise virtual corners where virtual corners are regions of high local curvature with respect to the axis system.

Preferably, for each of the objects, data is also generated containing one or more data points of the set of object data or a functional transform of one or more data points of the set of object data.

Preferably the N-dimensional object data is 3-dimensional object data, and the transformation function comprises, shifting the position of the origin to a new origin position and reorientating the axis system to a new axis orientation such that, in the new axis system (X', Y', Z'), defined by a first new axis (X’), a second new axis (Y’), and a third new axis (Z’), the new axis orientation, and new origin position, are a function of the coordinates of the apexes of the object triangle.

Preferably the data points are located on the surface of the object.

Preferably one or more feature data points comprise virtual texture corners where virtual texture corners are regions of high local curvature of light intensity of one or more light frequencies or frequency bands or a function of these on the surface of the object.

Preferably one or more of the data points of the set of object data comprise feature data points with coordinates pertaining to the apexes of the object triangle.

Preferably a unique object index is assigned for each of the objects.

Preferably a unique transformation index is assigned for each of the sides of each of the object triangles of each of the objects.

Preferably the data generated also includes data relating to the object index.

Preferably the data generated also includes data relating to the transformation index.

Preferably the data generated also includes data relating to the new axis system.

Preferably the data relating to the set of transformed object data comprises the feature data points of the set of transformed object data.

Alternatively the N-dimensional object data is 2-dimensional object data and the new axis system (X', Y') is defined by a first new axis (X') and a second new axis (Y'), and wherein the one or more of the coordinates (x, y) of the set of object data are transformed such that in the new axis system, the three apexes of the object triangle are coincident with the three apexes of a predefined triangle in the new axis system.

Preferably the new axis system is equivalent to the axis system.

Preferably the coordinates of the feature data points are calculated based on the data points of the set of object data.

Preferably the data relating to the set of transformed object data comprises the data points or a function of any of the data points of the set of transformed object data

Preferably the data generated relating to the set of transformed object data is stored in the leaves of a decision tree, where each decision is based upon the relative difference, positive or negative, between subsets of the generated data.

Preferably the coordinates of one or more feature data points of the set of object data are calculated by a method comprising steps of:

1. From the N-dimensional object data, deriving a region comprising data points
2. Calculating a base coordinate as a first function of the coordinates of the data points for the region

Preferably the data is generated for one scene and this data is generated as training data, and the data is also later generated for a different scene and this data is generated as test data, and the training data and test data is compared using an algorithm to recognise the one or more objects.

Preferably the data is generated for multiple scenes and this data is generated as training data, and the data is also later generated for a different scene and this data is generated as test data, and the training data and test data is compared using an algorithm to recognise the one or more objects.

Preferably the data points of a set of object data is used to form an interpolated or non-interpolated 3-dimensional mesh defined by mesh points, the coordinates of each mesh point corresponding to a coordinate or an interpolation of one or more of the coordinates of the data points, and each polygon of the surface mesh formed by proximate mesh points having associated with it one or more light intensity values derived as a function of the one or more light intensity values associated with nearby data points.

Preferably the one or more light intensity values correspond to the one or more light intensity values measured as coming from these coordinates.

Preferably the one or more sets of N-dimensional object data are derived by N-dimensionally imaging one of the one or more scenes from one or more viewpoints, for each of the viewpoints, a 2-dimensional image of the one or more objects is generated, each image comprising an array of pixels, the viewable point being characterised by one or more light intensity values and coordinates, either during the calculating of the coordinates for each viewpoint or after the calculating of the coordinates for all viewpoints, determining the set of data points of the set of object data for each of the objects and, either during the calculating of the coordinates for each viewpoint or after the calculating of the coordinates for all viewpoints, deriving the set of coordinates of features data points of the set of object data for each of the objects.

Preferably the light intensity values correspond to one or more light frequencies or frequency bands or a function of these frequencies or frequency bands within the scene.

Preferably the set of data points of a set of transformed object data is used to form an interpolated or non-interpolated N-dimensional mesh defined by mesh points, the coordinates of each mesh point corresponding to a coordinate or an interpolation of one or more of the coordinates of the data points, and each polygon of the surface mesh formed by proximate mesh points having associated with it one or more light intensity values derived as a function of the one or more light intensity values associated with nearby data points.

Preferably the virtual corners are a function of the coordinates of the data points of the object data.

Preferably a further new axis system (X'', Y'', Z'') is positioned and aligned such that a third further new axis (Z'') of the further new axis system is aligned perpendicular to the plane of the object triangle, and passing through the mid point between the two apexes at the extremities of the side, a first further new axis (X'') of the further new axis system is aligned parallel to the side, and a second further new axis (Y'') of the further new axis system is directed through the mid point in the direction of the third apex of the triangle, and the position and orientation of the first, second and third new axes of the new axis system are equivalent to a function of the position and orientation of the first, second and third further new axes of the further new axis system.

Preferably a further new axis system (X'', Y'', Z'') is positioned and aligned such a third new axis (Z') is aligned perpendicular to the plane of the object triangle, and passing through the mid point between the two apexes at the extremities of the side, the first new axis (X') is parallel to the side, and the second new axis (Y') axis is directed through the mid point in the direction of the third apex of the triangle.

Preferably the new axis orientation is a function of the 3-dimensional orientation of the side and the 3-dimensional orientation of the plane of the object triangle, and the new origin position is a function of the coordinates of one or more of the apexes.

Preferably the virtual texture corners are a function of the data points of the object data.

Preferably the feature data points of the set of transformed object data comprises coordinates pertaining to the transformed coordinates of the apexes of the object triangle.

Preferably the predefined triangle is an equilateral triangle.

Preferably the three apexes of the object triangle are made coincident with the three apexes of the predefined triangle by, scaling the object data such that the side of the object triangle is of same length as a predefined side of the predefined triangle, scaling the object data such that the perpendicular distance between the side of the object triangle and the third apex of the object triangle and perpendicular distance between the side of the predefined triangle and the third apex of the predefined triangle are the same, sheering the object data along an axis defined by the orientation of the side of the object triangle, and translating the object data such that the object triangle is centred about a predefined point.

Preferably a predefined side of the predefined triangle is parallel to the new X axis, and the three apexes of the object triangle are made coincident with the three apexes of the predefined triangle by, scaling the object data such that the side of the object triangle is of same length as the predefined side of the predefined triangle, rotating the object data such that the side of the object triangle is parallel with the new X axis, scaling the object data in the new Y axis direction such that the perpendicular distance between the side of the object triangle and the third apex of the object triangle and perpendicular distance between the side of the predefined triangle and the third apex of the predefined triangle are the same, sheering the object data along the new X-axis, and translating the object data such that the object triangle is centred about a predefined point.

Preferably one or more object features are calculated as a second function of the base coordinate and one or more data points of a region.

Preferably one more object features are base coordinates.

Preferably the data points for the region are contiguous for the region.

Preferably the base coordinate or first function is a geometric centroid of the data points for the region.

Preferably the data points for the region are on the boundary of the region.

Preferably the second function is a relative and/or absolute, minima and/or maxima detection function.

Preferably the one or more data points for the region are on the boundary of the region.

Preferably the algorithm comprises the comparison of the test data pertaining to one of the one or more sides of an object triangle with the training data pertaining to one of the one or more sides of the same or another object triangle.

Preferably the set of data points of the set of object data pertaining to each of the objects is isolated by determining boundaries between the one or more objects based on a boolean depth (distance) contrast map derived by applying an arbitrary threshold to a depth contrast map of the image, or a boolean depth gradient contrast map derived by applying an arbitrary threshold to a depth gradient contrast map of the image, or a boolean luminosity (light intensity) contrast map derived by applying an arbitrary threshold to a luminosity contrast map of the image, or any function or linear or non-linear combination of these maps.

Preferably the position and orientation of one viewpoint is set to an absolute position and orientation in the space, thereby determining both the position of the origin and the orientation of the axis system and the absolute positions and orientations of all viewpoints.

Preferably the viewable point resides on one or more of the objects.

Optionally the N-dimensional object data is 3-dimensional, the viewpoints are of defined relative positions and orientations in the space, each pixel corresponding to a viewable point in the scene at a distance from the viewpoint, and the coordinates are 3-dimensional (x, y, z) coordinates in space.

Preferably for each viewpoint, the imaging comprises creating at least two 2-dimensional images from two different viewpoints, either sequentially or using at least two cameras, and a parallax offset between the positions in the resulting pixels arrays of the corresponding viewable points, and/or the difference between their corresponding one or more light intensity values is used to calculate the distance.

Preferably the function of the data points of the set of transformed object data are snapshot N-dimensional mesh surface data points calculated by imaging the N-dimensional mesh from a particular point of view.

Optionally the new axis systems are equivalent to the axis systems, and an equivalent transformation function is applied to the coordinates without using a new axis system to describe this transformation.

Preferably the predefined point is the new origin (0,0).

Optionally the new axis system is equivalent to the axis system.

Preferably the contiguous data points for the region have a similar light intensity value or a similar third function of their light intensity values.

Preferably the coordinate (x, y, z) of each viewable point in space is based on the location of the pixel in the array, the distance between the viewable point and the viewpoint, and the position, orientation, and viewing properties of the viewpoint.

Preferably the snapshot N-dimensional mesh surface data points are calculated as the coordinates or array positions and one or more light intensity values of data points in a 2-dimensional array of data points generated by interpolating the mesh surface at particular first new axis (X’) and second new axis (Y’) coordinate intervals, each data point corresponding to a point on or off of the N-dimensional mesh surface and having one or more light intensity values derived as a function of the light intensity values of data points proximate to the point, and a coordinate derived as a function of the coordinates of the data points proximate to the point.

Preferably the snapshot N-dimensional mesh surface data points are calculated as the coordinates or array positions and one or more light intensity values of pixels in the 2-dimensional image generated when a virtual mesh viewpoint is aligned to the third new axis (Z’), perpendicular to the first new axis (X') and second new axis (Y') , or aligned at a predetermined angular deviation from the third new axis (Z’), with the mesh viewpoint positioned at the new origin, or at a predetermined offset deviation from the new origin, each pixel corresponding to a mesh viewable point on or off of the N-dimensional mesh surface and having one or more light intensity values derived as a function of the light intensity values of data points proximate to the mesh viewable point, and a coordinate derived as a function of the coordinates of the data points proximate to the mesh viewable point.

Preferably the third function is a luminosity contrast function.

Preferably the positions and orientations of at least one of the one or more viewpoints are calculated based on a functional transformation of the coordinates of the data points of one or more sets of object data or of the positions and orientations of one or more viewpoints, or the viewing properties of one or more viewpoints.

Preferably the viewing properties of the viewpoint comprise a view width angle and a view height angle.

Preferably the data points of the snapshot N-dimensional mesh data points have their one or more light intensity values set to an arbitrary one or more light intensity values if, in the X' Y' space, their coordinates lie outside of the triangle formed by the coordinates of the feature data points of the set of transformed object data pertaining to the transformed apexes of the object triangle.

Preferably the transformation function is performed using hardware acceleration, such as in a PC graphics card.

Preferably the data relating to the set of transformed object data is generated using hardware acceleration, such as in a PC graphics card.

Brief Description of Drawings

Fig 1. shows a cubic object residing a 3-dimensional space and viewed from two viewpoints,

Fig 2. shows a flow diagram of the data generation method according to the present invention,

Fig 3. shows an image produced from one of the viewpoints in Fig. 2

Fig 4. shows the data points produced from the image in Fig. 3

Fig 5. shows an RGB map of the image in Fig. 3,

Fig 6. shows a luminosity map based on the RGB map in Fig. 5,

Fig 7. shows a luminosity contrast map based on the luminosity map in Fig. 6,

Fig 8. shows a depth map based on the image in Fig. 3 and other depth data,

Fig 9. shows a depth contrast map based on the depth map in Fig. 8,

Fig 10. shows a depth gradient map based on the depth map in Fig. 8,

Fig 11. shows a depth gradient contrast map based on the depth gradient map in Fig. 10 and the depth contrast map in Fig 9,

Fig 12. shows a region based upon the luminosity contrast map in Fig. 7,

Fig 13. shows a combination of relative minimas and maximas from the centroid of the region in Fig 12,

Fig 14. shows the corners map in Fig. 13, also with relevant object triangles,

Fig 15. shows the start of the axis transformation method with the object triangle in the original coordinates system,

Fig 16. shows step A of the axis transformation method in which a third new axis (Z’) is aligned perpendicular to the plane of the object triangle,

Fig 17. shows step B of the axis transformation method in which the third new axis (Z’) is positioned such that it passes through the mid-point between the two apexes at the extremities of the side,

Fig 18. shows step C of the axis transformation method in which a first new axis (X’) is aligned parallel to the side, and a second new axis (Y’) is directed through the mid point in the direction of the third apex of the triangle,

Fig 19. shows step D of the axis transformation method in which the coordinates (x, y, z) of the object data are transformed into transformed coordinates (x', y', z') in the new axis system,

Fig 20. interpolated 3-dimensional Mesh with Data Points shown

Fig 21. shows an interpolated 3-dimensional mesh with light intensity values of the mesh surface polygons,

Fig 22. shows the interpolated 3-dimensional mesh in Fig. 20 with object triangles included,

Fig 23. shows a snapshot of the interpolated 3-dimensional mesh in Fig. 20, and

Fig 24. shows the a method of calculating the distance of viewable points using a parallax technique.

Fig 25. shows the start of the Alternative coordinates transformation method with the object triangle and the predefined equilateral triangle shown with respect to both the original coordinates system and the new coordinates system, where a predefined side of the predefined triangle is parallel to the new X axis.

Fig 26. shows step A of the Alternative coordinates transformation method in which the object data is scaled such that the side of the object triangle is of same length as a predefined side of the predefined triangle.

Fig 27. shows step B of the Alternative coordinates transformation method in which the object data is rotated such that the side of the object triangle is parallel with the new X axis.

Fig 28. shows step C of the Alternative coordinates transformation method in which the object data is scaled in the new Y axis direction such that the perpendicular distance between the side of the object triangle and the third apex of the object triangle and perpendicular distance between the side of the predefined triangle and the third apex of the predefined triangle are the same.

Fig 29. shows step D of the Alternative coordinates transformation method in which the object data is sheered along the new X-axis.

Fig 30. shows step E of the Alternative coordinates transformation method in which the object data is translated such that the object triangle is centred about a predefined point, the centre of the predefined triangle.

Best Mode for Carrying out the Invention

Referring to Fig. 1, the data generating method according to the present invention will be described based, for simplicity, on a single cubic object 1 residing in a single scene 2 in a 3-dimensional cartesian space defined by an X, Y, Z axis system passing through an origin 3. Fig. 1 also shows two alternative viewpoints 4 and 5 of object 1, each with respective viewpoint positions 6 and 7 and respective viewpoint orientations 8 and 9 in the space. It will be recognised by those skilled in the art of object recognition that the same method could also be used to generate data pertinent to an object where multiple objects reside in one or more scenes.

Referring to the flow diagram in Fig. 2, it can be seen that the method described can therefore be “looped through” for more than one scene, for more than one viewpoint and for more than one object. For example, it might be necessary in a particular application for a vision system of an industrial robot to be able to recognise a set of three objects, say objects O1, O2 and O3 in relatively complex scenes in which one or more of the objects O1, O2 and O3 are resident. The vision system could, for example, be trained by arranging the vision system to successively view O1 in a first scene from a number of viewpoint positions and orientations in that scene, then view O2 in a second scene also from a number of viewpoint positions and orientations, and then view O3 in the third scene also from a number of viewpoint positions and orientations. The transformed object data generated for each object according to the present invention would then constitute “training data”.

After this training process, the capability of the object recognition system of the industrial robot could be measured by arranging the (or another) vision system to view a scene comprising one or more of the objects O1, O2 and O3, plus also potentially previous “untrained” objects introduced in an attempt to contaminate the scene. The method according to the present invention allows the segmentation of the transformed object data pertinent to a particular object (say O2) and this “testing data” to be compared to the “training data” for that object (O2), in order to quantifiably measure the “recognition level’ of that object.

However, for reason described above, the method will herein be described by passing through the data generation procedure once, based on a single object 1 residing in a single scene 2 and viewed from a single viewpoint 4. For clarity, repeatable procedures will be identified in the description by the designation “Perform the following procedure x” and “end of procedure x”.

Perform the following procedure 1 for each scene.

Procedure 1 comprises of 4 steps.

<u>Step 1:</u>

Set up a digital camera (or other digital imaging system) at an arbitrary original viewpoint 4, with viewpoint position 6 and viewpoint orientation 8 in space, to image the scene 2, with known optics parameters, for example view width angle 10 and view height angle 11. Also set a set 2-dimensional pixel resolution for the camera.

Perform the following procedure 1.1 for each viewpoint.

Each new viewpoint during each pass through this loop must be at a known relative position and orientation from the original viewpoint. This loop firstly involves generation of a 2-dimensional image 12 of object 1 shown in Fig. 3, comprising an array of pixels, each pixel 14 (for example) corresponding to a viewable point 13 (for example) in scene 2. Viewable points are shown here in Fig. 3 as all being positioned on the surface of object 1. However, in the general sense, viewable points can also be located somewhere else in scene 2, not on object 1. In this embodiment each pixel has associated with it Red-Green-Blue (RBG) light intensity values, however other well known colour or monochrome light intensity value parameter sets could also be employed.

A distance 15 of each viewable point 13 from viewpoint 4 is now calculated using a parallax technique. This is facilitated by creating at least two 2-dimensional images from two different sub-viewpoints, each sub-viewpoint itself of known position and orientation and, by implication, separated by a known separation 16. Then, either sequentially or using different cameras, distance 15 can be calculated by techniques well known in the art, using the parallax offset between the differential positions of the corresponding viewable point 13 in the resulting pixels arrays 12.

Now referring in more detail to one particular embodiment of this technique in Figs. 24(a) - 24(d), the calculation of distance 15 involves creation of a contrast map (refer to Fig. 24(a)), and then performing sub-pixel edge detection on this contrast map (refer to Fig. 24(b)). This is repeated for a number of pixel value offset positions, adjusting the position, in the direction of the sub-viewpoint separation 16, of pixel values in one sub-image (refer to Fig. 24(c)), testing the sub-image of both sub-viewpoints, and measuring how similar they (refer to Fig. 24(d)). Upon locating the most similar sub-image, distance 15 between viewable point 13 of the surface of object 1 and viewpoint 4 can be calculated based upon their separation pixel value offset in the sub-image.

A depth map as shown in Fig. 8 can now be generated based on the distances calculated for all the viewable points 13 as visible from viewpoint 4.

The coordinates (x, y, z) in space 2 of each viewable point 13 can now be calculated based on the location of the corresponding pixel 14 in the array, its corresponding distance 15, viewpoint position 6 and viewpoint orientation 8 in space 2, and the viewing properties of viewpoint 4 such as the view width angle 10 and the view height angle 11. Data points 17 are generated for object 1 based on the "view" from viewpoint 4 as shown in Fig. 4.

Based on the light intensity values (RBG values in this case) and corresponding coordinates of each pixel 14 in image 12, a set of "object features" can be now identified. In the embodiment described herein in respect to the present invention one type of object feature, specifically "corners" of the object or regions of high curvature on object 1, are derived as follows.

Using the RGB map shown in Fig. 5 (the light intensity RGB values of every pixel in image 12), a corresponding luminosity map shown in Fig. 6 is generated, in which each luminosity map pixel value is equal to the red plus green plus blue component values of the corresponding RGB map pixel.

Using the luminosity map, a luminosity contrast map shown in Fig. 7 is generated, in which each pixel value is equal to a function of the difference in luminosity between neighbouring pixels.

Also, using the depth map already described in reference to Fig. 8 (the distance values of every pixel in image 12), a depth contrast map is generated shown in Fig. 9, in which each pixel value is equal to a function of the difference in depth between neighbouring pixels.

Also using the depth map, a depth gradient map is generated shown in Fig. 10, in which each pixel value has a vector associated with it which is equal to the change in depth between neighbouring pixels.

Using this depth gradient map, a depth gradient contrast map is generated shown in Fig. 11, in which each pixel value is equal to a function of the difference in depth gradient (in all directions) between neighbouring pixels.

At this point in the procedure, data points corresponding to unique objects may be isolated based upon for example contiguous regions of zero depth contrast. For every object isolated, a unique object index is assigned. It should be noted that if procedure 1.1 is executed for more than one viewpoint, the indices of the objects isolated with the indices of the objects isolated for previous viewpoints are mapped based upon the coordinates of the viewable points in the current image and the coordinates of the viewable points in previous images and their corresponding object indices.

A function of the original object data, such as the luminosity contrast map, the depth contrast map, or depth gradient contrast map, is then used to identify regions 40 shown in Fig. 12. The luminosity contrast map in Fig. 7 is chosen to be used to generate a single contiguous region of null contrast.

A point 41 is then calculated based upon one or more points contained within this region. The point calculated is chosen to be the centroid of the region, the average position (x, y, z) of all pixels in the region (or all pixels in the contiguous region's outer boundary, which happens to provide the same centroid position in this particular case).

The coordinates (x,y,z) of the centroid 41 provides an initial object feature. Additional object features may be calculated based upon a function of the position of the point 41, and the coordinates of all other points in the region. Sequentially, taking adjacent points, the position (x,y,z) of every point 42, 43, 44 on the outer boundary of the region 40 is then compared to the position of the centroid 41 (x,y,z) measuring a distance 45, and it is noted where relative minimas and maximas 43 occur in this distance 42. These relative minimas and maximas are used to generate coordinates (x,y,z) of additional object features 18. In this particular case, the additional object features identified are virtual corners of the object.

For each of the object isolated from the viewpoints, a set of 3-dimensional “object data” is created. For every object isolated from this viewpoint, add to the relevant set of object data (a) a set of coordinates (x, y, z) of object features, virtual corners 18 in this case, and (b) a set of data points where each data point contains the 3-dimensional coordinates (x, y, z) of the respective viewable point 13 in image 12 pertaining to object 1 when viewed from viewpoint 4, and it's associated light intensity values, three RGB values in this case.

End of procedure 1.1.

<u>Step 2:</u>

Referring to Fig. 14, for each of the objects permutations of the coordinates of virtual corners 18 of the set of object data pertaining to object 1 are now grouped as apexes of object triangles, for example the three apexes 19, 20 and 21 of object triangle 22 bounded by three sides 23, 24 and 25. The triangles, twelve in the case of Fig. 14, are differently 3-dimensionally orientated in space 2. The specific orientation of plane 26 which is coplanar with object triangle 22 is fully defined by the coordinates of the three respective apexes 19, 20 and 21.

Step 3:

For each of the one or more of the sides 23, 24 and 25 of each of the object triangles 22 of each of the objects 1 for each of the viewpoints, a unique transformation index assigned, and the coordinates of the set of object data are transformed into transformed coordinates in a new axis system, where the transformation function is a function of the coordinates of the apexes of the object triangle.

The following transformation procedure is followed.

The transformation function comprises, shifting the position of the origin to a new origin position and reorientating the axis system to a new axis orientation such that, in the new axis system (X', Y', Z'), defined by a first new axis (X’), a second new axis (Y’), and a third new axis (Z’), the new axis orientation, and new origin position, are a function of the coordinates of the apexes of the object triangle.

Referring to the sequence shown in Fig 15., 16, 17 and 18, the origin 3 is now shifted to a new origin position 27 and reorientated to a new axis orientation 28 such that, in the new X', Y', Z' axis system, a third new axis (Z’) is aligned perpendicular to the plane of object triangle (Fig. 16), this third new axis (Z’) passes through a mid-point 29 between the apexes 19 and 21 at the extremities of side 25 (Fig. 17), a first new axis (X’) of the new axis system is aligned parallel to side 25, and a second new axis (Y’) of the new axis system is directed through mid-point 28 in the direction 35 of the third apex 20 of the triangle (Fig. 18).

The coordinates (x, y, z) of data points of the set of object data and the coordinates of the object triangle apexes (coordinates of object features of the set of object data pertaining to the apexes of the object triangle) are therefore appropriately transformed into new coordinates (x', y', z') in the new X’, Y’, Z’ axis system, hence forming a set of transformed object data as shown in Fig. 19.

Alternatively, where only 2-dimensional object data is available (Eg an image of the object from a viewpoint), the transformation function may involve the following.

The new axis system (X', Y') is defined by a first new axis (X’) and a second new axis (Y’), and the coordinates (x, y) of the set of object data are transformed such that in the new axis system, the three apexes of the object triangle are coincident with the three apexes of a predefined triangle in the new axis system.

Referring to the sequence shown in Fig 25., 26, 27, 28, 29, and 30, the three apexes of the object triangle are made coincident with the three apexes of a predefined equilateral triangle 36, where a predefined side 39 of the predefined triangle is parallel to the new X axis (Fig. 25), by, scaling the object data such that the side 25 of the object triangle is of same length 37 as a predefined side of the predefined triangle (Fig. 26), rotating the object data such that the side of the object triangle is parallel with the new X axis (Fig. 27), scaling the object data in the new Y axis direction such that the perpendicular distance 38 between the side of the object triangle and the third apex of the object triangle and perpendicular distance between the side of the predefined triangle and the third apex of the predefined triangle are the same (Fig. 28), sheering the object data along the new X-axis (Fig. 29), and translating the object data such that the object triangle is centred about a predefined point, the centre of the predefined triangle (Fig. 30).

Step 4:

Referring to Figs. 20 and 21, for each of the new axis transformations, an interpolated 3-dimensional surface mesh 30 is formed defined by mesh points 31, the coordinates of each mesh point 31 corresponding the coordinates of a data point from the set of transformed object data associated with the object and that particular axis transformation (31), or an interpolation of one or more of the coordinates of the data points (31B). Each polygon 32 of the surface mesh 30 formed by proximate mesh points 31 and 31B have associated with it the light intensity values (henceforth referred to as “RGB values” in this embodiment) derived as a function of the RGB values associated with nearby data points.

Referring to Figs. 22 and 23, for each of the new axis transformations, a set of snapshot mesh data points 33 are generated, where the snapshot 3-dimensional mesh surface data points 33 are calculated as the coordinates (or array positions) and RGB values of pixels in the 2-dimensional image generated when, in computer graphics, a virtual mesh viewpoint is aligned to the Z’ axis, with the mesh viewpoint positioned at the respective new origin position 27, each pixel corresponding to a mesh viewable point on the 3-dimensional mesh surface 34 and having RGB values derived as a function of the RGB values of data points proximate to the mesh viewable point, and coordinates derived as a function of the coordinates of the data points proximate to the mesh viewable point 31. A viewable mesh depth map (a 2-dimensional array of Z’ values of each of the mesh viewable points 31), and a viewable mesh RGB map (a 2-dimensional array of RGB values of each of the mesh viewable points) are then generated. It may be noted that when a neural network comparison algorithm is used (see below) and the data currently being generated is training data, multiple sets of snapshot mesh data points may be generated for every new axis transformation, each with slight positional or orientation variations, to improve the performance of the neural network.

For each of the new axis transformations, the viewable mesh RGB map(s), the viewable mesh depth map(s), the transformed coordinates of the object triangle apexes (those coordinates of the coordinates of object features of the set of transformed object data pertaining to the apexes of the object triangle), the object index, and the transformation index, are recorded as data.

End of procedure 1.

As mentioned at the start of the description of this embodiment, the data recording method can be executed sequentially for multiple scenes, each with multiple objects and viewpoints. Training data can be initially recorded and this training data later compared with test data, also recorded using the method, using algorithms to match (recognise) the object in the test data with objects from the training data.

In this embodiment, this method of comparison of the training data with the test data is as follows.

For each of the one or more sides of each of the object triangles of the objects of the test data, for each of the one or more sides of each of the object triangles of each of the objects of the training data, the data pertaining to the side of the test data is compared with the data pertaining to the side of the training data. This is achieved by comparing the transformed coordinates of the object triangle apexes (those coordinates of the coordinates of object features of the set of transformed object data pertaining to the apexes of the object triangle) of the test data and training data. The actual comparison is performed by comparing the distance each apex in the test data object triangle is away from the corresponding apex in the training data object triangle. For each of the one or more sides of each of the object triangles of the objects of the test data the maximum comparison accuracy value experienced across all training data sets is calculated, and the transformation indices of the training data where their maximum comparison accuracy is above a certain arbitrary value is recorded. This creates a subset of the test data called in this specification the “geometry matched test data” (GMTD), and for each transformation index of the geometry matched test data, the transformation indices of the object triangle side(s) of the training data that gave comparison accuracies above the certain arbitrary value, called in this specification the “geometry matched test data training data matches” (GMTDTDM) are also recorded.

Now light intensity recognition is performed on those testing data object triangle sides and their corresponding training object triangle sides which were found to have a high geometric comparison accuracy i.e. the GMTD and their corresponding GMTDTDM, by performing the following procedure.

As described below, a network based artificial intelligence algorithm is used to train a decision tree with the training data. In this embodiment the input values into the network are the values of a viewable mesh RGB map and/or the values of a colour saturation contrast map of the viewable mesh RGB map and/or the values of a viewable mesh depth map, and the output values of the network are a function of an object index or an object transformation index (for example the object index x 3 + the transformation index).

For each of the one or more sides of each of the object triangles of each of the objects of the training data, the network is trained with an experience, where the input values are the values of the viewable mesh RGB map(s) and/or the values of the colour saturation contrast map(s) of the viewable mesh RGB map(s) and/or the values of the viewable mesh depth map(s) from the training data, and the output value is the training output value value (for example the object index x 3 + the transformation index).

The network based artificial intelligence algorithm can now be used to test the network against the testing data object(s), thereby determining whether or not the testing object(s) is/are recognised and which of the trained objects this testing data object(s) corresponds to.

For each of the one or more sides of each of the object triangles of the object of the GMTD, and for every possible training output value, the testing data experience is tested against the trained network, where the input values are the values of the viewable mesh RGB map and/or the values of the colour saturation contrast map of the viewable mesh RGB map and/or the values of the viewable mesh depth map from the testing data, and the output is the training output value, where the testing data object (index) equates to the training data object (index).

It is also verified that the object triangle side (transformation index) recognised in the light intensity recognition phase was also recognised as the same object triangle side (transformation index) in the geometric recognition phase. The transformation indices of the object triangle sides of the GMTD and training data matched by use of the network in the light intensity recognition phase are compared with the transformation indices of GMTD and each of their GMTDTDM matched in the geometric recognition phase.

An object is recognised based upon a function of the number of object triangle sides associated with that object that were recognised.

The term “comprising” as used herein is used in the inclusive sense of “including” or “having” and not in the exclusive sense of “consisting only of”.

Claims

The claims defining the invention are as follows:

Claim 1

A method for generating data for one or more objects residing in one or more scenes in a space defined by an axis system passing through an origin, comprising the steps of:

1. for each of the objects, deriving a set of N-dimensional object data comprising data points, each data point defined by N-dimensional coordinates, one or more of the data points being feature data points with coordinates corresponding to coordinates of object features;
2. for each of the objects, grouping permutations of the coordinates of feature data points of the set of object data as the coordinates of apexes of one or more object triangles, each object triangle comprising three sides and three apexes and defining a plane;
3. for each of one or more of the sides of each of the object triangles of each of the objects, transforming the coordinates of one or more of the data points of the set of object data into transformed coordinates in a new axis system, where the transformation function is a function of the coordinates of the apexes of the object triangle, thereby forming a set of transformed object data; and
4. for each of the one or more sides of each of the object triangles of each of the objects, generating data relating to the set of transformed object data.

Claim 2

A method as claimed in Claim 1, wherein one or more data points comprise an associated one or more light intensity values.

Claim 3

A method as claimed in Claim 1 wherein one or more feature data points comprise virtual corners where virtual corners are regions of high local curvature with respect to the axis system.

Claim 4

A method as claimed in Claim 1, wherein for each of the objects, data is also generated containing one or more data points of the set of object data or a functional transform of one or more data points of the set of object data.

Claim 5

A method as claimed in Claim 1, wherein the N-dimensional object data is 3-dimensional object data, and the transformation function comprises, shifting the position of the origin to a new origin position and reorientating the axis system to a new axis orientation such that, in the new axis system (X', Y', Z'), defined by a first new axis (X’), a second new axis (Y’), and a third new axis (Z’), the new axis orientation, and new origin position, are a function of the coordinates of the apexes of the object triangle.

Claim 6

A method as claimed in Claim 1 wherein the data points are located on the surface of the object.

Claim 7

A method as claimed in Claim 1 wherein one or more feature data points comprise virtual texture corners where virtual texture corners are regions of high local curvature of light intensity of one or more light frequencies or frequency bands or a function of these on the surface of the object.

Claim 8

A method as claimed in Claim 1, wherein one or more of the data points of the set of object data comprise feature data points with coordinates pertaining to the apexes of the object triangle.

Claim 9

A method as claimed in Claim 1 wherein a unique object index is assigned for each of the objects.

Claim 10

A method as claimed in Claim 1 wherein a unique transformation index is assigned for each of the sides of each of the object triangles of each of the objects.

Claim 11

A method as claimed in Claim 9 wherein the data generated also includes data relating to the object index.

Claim 12

A method as claimed in Claim 10 wherein the data generated also includes data relating to the transformation index.

Claim 13

A method as claimed in Claim 1 wherein the data generated also includes data relating to the new axis system.

Claim 14

A method as claimed in Claim 1, wherein the data relating to the set of transformed object data comprises the feature data points of the set of transformed object data.

Claim 15

A method as claimed in Claim 1, wherein the N-dimensional object data is 2-dimensional object data and the new axis system (X', Y') is defined by a first new axis (X’) and a second new axis (Y’), and wherein the one or more of the coordinates (x, y) of the set of object data are transformed such that in the new axis system, the three apexes of the object triangle are coincident with the three apexes of a predefined triangle in the new axis system.

Claim 16

A method as claimed in Claim 1, wherein the new axis system is equivalent to the axis system.

Claim 17

A method as claimed in Claim 1 wherein the coordinates of the feature data points are calculated based on the data points of the set of object data.

Claim 18

A method as claimed in Claim 1, wherein the data relating to the set of transformed object data comprises the data points or a function of any of the data points of the set of transformed object data

Claim 19

A method as claimed in Claim 1 wherein the data generated relating to the set of transformed object data is stored in the leaves of a decision tree, where each decision is based upon the relative difference, positive or negative, between subsets of the generated data.

Claim 20

A method as claimed in Claim 1, wherein the coordinates of one or more feature data points of the set of object data are calculated by a method comprising steps of:

1. From the N-dimensional object data, deriving a region comprising data points
2. Calculating a base coordinate as a first function of the coordinates of the data points for the region

Claim 21

A method as claimed in Claim 1 wherein the data is generated for one scene and this data is generated as training data, and the data is also later generated for a different scene and this data is generated as test data, and the training data and test data is compared using an algorithm to recognise the one or more objects.

Claim 22

A method as claimed in Claim 1 wherein the data is generated for multiple scenes and this data is generated as training data, and the data is also later generated for a different scene and this data is generated as test data, and the training data and test data is compared using an algorithm to recognise the one or more objects.

Claim 23

A method as claimed in Claim 2 wherein the data points of a set of object data is used to form an interpolated or non-interpolated 3-dimensional mesh defined by mesh points, the coordinates of each mesh point corresponding to a coordinate or an interpolation of one or more of the coordinates of the data points, and each polygon of the surface mesh formed by proximate mesh points having associated with it one or more light intensity values derived as a function of the one or more light intensity values associated with nearby data points.

Claim 24

A method as claimed in Claim 2 wherein the one or more light intensity values correspond to the one or more light intensity values measured as coming from these coordinates.

Claim 25

A method as claimed in Claim 2, wherein the one or more sets of N-dimensional object data are derived by N-dimensionally imaging one of the one or more scenes from one or more viewpoints, for each of the viewpoints, a 2-dimensional image of the one or more objects is generated, each image comprising an array of pixels, the viewable point being characterised by one or more light intensity values and coordinates, either during the calculating of the coordinates for each viewpoint or after the calculating of the coordinates for all viewpoints, determining the set of data points of the set of object data for each of the objects and, either during the calculating of the coordinates for each viewpoint or after the calculating of the coordinates for all viewpoints, deriving the set of coordinates of features data points of the set of object data for each of the objects.

Claim 26

A method as claimed in Claim 2 where the light intensity values correspond to one or more light frequencies or frequency bands or a function of these frequencies or frequency bands within the scene.

Claim 27

A method as claimed in Claim 2 wherein the set of data points of a set of transformed object data is used to form an interpolated or non-interpolated N-dimensional mesh defined by mesh points, the coordinates of each mesh point corresponding to a coordinate or an interpolation of one or more of the coordinates of the data points, and each polygon of the surface mesh formed by proximate mesh points having associated with it one or more light intensity values derived as a function of the one or more light intensity values associated with nearby data points.

Claim 28

A method as claimed in Claim 3 wherein the virtual corners are a function of the coordinates of the data points of the object data.

Claim 29

A method as claimed in Claim 5, wherein a further new axis system (X'', Y'', Z'') is positioned and aligned such that a third further new axis (Z'') of the further new axis system is aligned perpendicular to the plane of the object triangle, and passing through the mid point between the two apexes at the extremities of the side, a first further new axis (X'') of the further new axis system is aligned parallel to the side, and a second further new axis (Y'') of the further new axis system is directed through the mid point in the direction of the third apex of the triangle, and the position and orientation of the first, second and third new axes of the new axis system are equivalent to a function of the position and orientation of the first, second and third further new axes of the further new axis system.

Claim 30

A method as claimed in Claim 5, wherein a further new axis system (X'', Y'', Z'') is positioned and aligned such a third new axis (Z') is aligned perpendicular to the plane of the object triangle, and passing through the mid point between the two apexes at the extremities of the side, the first new axis (X') is parallel to the side, and the second new axis (Y') axis is directed through the mid point in the direction of the third apex of the triangle.

Claim 31

A method as claimed in Claim 5, wherein the new axis orientation is a function of the 3-dimensional orientation of the side and the 3-dimensional orientation of the plane of the object triangle, and the new origin position is a function of the coordinates of one or more of the apexes.

Claim 32

A method as claimed in Claim 7 wherein the virtual texture corners are a function of the data points of the object data.

Claim 33

A method as claimed in Claim 14 wherein the feature data points of the set of transformed object data comprises coordinates pertaining to the transformed coordinates of the apexes of the object triangle.

Claim 34

A method as claimed in Claim 15, wherein the predefined triangle is an equilateral triangle.

Claim 35

A method as claimed in Claim 15, wherein the three apexes of the object triangle are made coincident with the three apexes of the predefined triangle by, scaling the object data such that the side of the object triangle is of same length as a predefined side of the predefined triangle, scaling the object data such that the perpendicular distance between the side of the object triangle and the third apex of the object triangle and perpendicular distance between the side of the predefined triangle and the third apex of the predefined triangle are the same, sheering the object data along an axis defined by the orientation of the side of the object triangle, and translating the object data such that the object triangle is centred about a predefined point.

Claim 36

A method as claimed in Claim 15, wherein a predefined side of the predefined triangle is parallel to the new X axis, and the three apexes of the object triangle are made coincident with the three apexes of the predefined triangle by, scaling the object data such that the side of the object triangle is of same length as the predefined side of the predefined triangle, rotating the object data such that the side of the object triangle is parallel with the new X axis, scaling the object data in the new Y axis direction such that the perpendicular distance between the side of the object triangle and the third apex of the object triangle and perpendicular distance between the side of the predefined triangle and the third apex of the predefined triangle are the same, sheering the object data along the new X-axis, and translating the object data such that the object triangle is centred about a predefined point.

Claim 37

A method as claimed in Claim 20, wherein one or more object features are calculated as a second function of the base coordinate and one or more data points of a region.

Claim 38

A method as claimed in Claim 20, wherein one more object features are base coordinates.

Claim 39

A method as claimed in Claim 20, wherein the data points for the region are contiguous for the region.

Claim 40

A method as claimed in Claim 20, wherein the base coordinate or first function is a geometric centroid of the data points for the region.

Claim 41

A method as claimed in Claim 20, wherein the data points for the region are on the boundary of the region.

Claim 42

A method as claimed in Claim 20, wherein the second function is a relative and/or absolute, minima and/or maxima detection function.

Claim 43

A method as claimed in Claim 20, wherein the one or more data points for the region are on the boundary of the region.

Claim 44

A method as claimed in Claim 21 or Claim 22 wherein the algorithm comprises the comparison of the test data pertaining to one of the one or more sides of an object triangle with the training data pertaining to one of the one or more sides of the same or another object triangle.

Claim 45

A method as claimed in Claim 25, wherein the set of data points of the set of object data pertaining to each of the objects is isolated by determining boundaries between the one or more objects based on a boolean depth (distance) contrast map derived by applying an arbitrary threshold to a depth contrast map of the image, or a boolean depth gradient contrast map derived by applying an arbitrary threshold to a depth gradient contrast map of the image, or a boolean luminosity (light intensity) contrast map derived by applying an arbitrary threshold to a luminosity contrast map of the image, or any function or linear or non-linear combination of these maps.

Claim 46

A method as claimed in Claim 25, wherein the position and orientation of one viewpoint is set to an absolute position and orientation in the space, thereby determining both the position of the origin and the orientation of the axis system and the absolute positions and orientations of all viewpoints.

Claim 47

A method as claimed in Claim 25, wherein the viewable point resides on one or more of the objects.

Claim 48

A method as claimed in Claim 25, where in the N-dimensional object data is 3-dimensional, the viewpoints are of defined relative positions and orientations in the space, each pixel corresponding to a viewable point in the scene at a distance from the viewpoint, and the coordinates are 3-dimensional (x, y, z) coordinates in space.

Claim 49

A method as claimed in Claim 25 wherein, for each viewpoint, the imaging comprises creating at least two 2-dimensional images from two different viewpoints, either sequentially or using at least two cameras, and a parallax offset between the positions in the resulting pixels arrays of the corresponding viewable points, and/or the difference between their corresponding one or more light intensity values is used to calculate the distance.

Claim 50

A method as claimed in Claim 27 wherein the function of the data points of the set of transformed object data are snapshot N-dimensional mesh surface data points calculated by imaging the N-dimensional mesh from a particular point of view.

Claim 51

A method as claimed in Claims 4, 5, 6 and 55, wherein the new axis systems are equivalent to the axis systems, and an equivalent transformation function is applied to the coordinates without using a new axis system to describe this transformation.

Claim 52

A method as claimed in Claim 35 and Claim 36, wherein the predefined point is the new origin (0,0).

Claim 53

A method as claimed in Claim 35 and Claim 36, wherein the new axis system is equivalent to the axis system.

Claim 54

A method as claimed in Claim 39, wherein the contiguous data points for the region have a similar light intensity value or a similar third function of their light intensity values.

Claim 55

A method as claimed in Claim 48, wherein the coordinate (x, y, z) of each viewable point in space is based on the location of the pixel in the array, the distance between the viewable point and the viewpoint, and the position, orientation, and viewing properties of the viewpoint.

Claim 56

A method as claimed in Claim 50 wherein the snapshot N-dimensional mesh surface data points are calculated as the coordinates or array positions and one or more light intensity values of data points in a 2-dimensional array of data points generated by interpolating the mesh surface at particular first new axis (X’) and second new axis (Y’) coordinate intervals, each data point corresponding to a point on or off of the N-dimensional mesh surface and having one or more light intensity values derived as a function of the light intensity values of data points proximate to the point, and a coordinate derived as a function of the coordinates of the data points proximate to the point.

Claim 57

A method as claimed in Claim 50 wherein the snapshot N-dimensional mesh surface data points are calculated as the coordinates or array positions and one or more light intensity values of pixels in the 2-dimensional image generated when a virtual mesh viewpoint is aligned to the third new axis (Z’), perpendicular to the first new axis (X') and second new axis (Y') , or aligned at a predetermined angular deviation from the third new axis (Z’), with the mesh viewpoint positioned at the new origin, or at a predetermined offset deviation from the new origin, each pixel corresponding to a mesh viewable point on or off of the N-dimensional mesh surface and having one or more light intensity values derived as a function of the light intensity values of data points proximate to the mesh viewable point, and a coordinate derived as a function of the coordinates of the data points proximate to the mesh viewable point.

Claim 58

A method as claimed in Claim 54, wherein the third function is a luminosity contrast function.

Claim 59

A method as claimed in Claim 55 wherein the positions and orientations of at least one of the one or more viewpoints are calculated based on a functional transformation of the coordinates of the data points of one or more sets of object data or of the positions and orientations of one or more viewpoints, or the viewing properties of one or more viewpoints.

Claim 60

A method as claimed in Claim 55, wherein the viewing properties of the viewpoint comprise a view width angle and a view height angle.

Claim 61

A method as claimed in Claim 57 and Claim 56 wherein data points of the snapshot N-dimensional mesh data points have their one or more light intensity values set to an arbitrary one or more light intensity values if, in the X' Y' space, their coordinates lie outside of the triangle formed by the coordinates of the feature data points of the set of transformed object data pertaining to the transformed apexes of the object triangle.

Claim 62

A method as claimed in Claim 1 wherein the transformation function is performed using hardware acceleration, such as in a PC graphics card.

Claim 63

A method as claimed in Claim 1 wherein the data relating to the set of transformed object data is generated using hardware acceleration, such as in a PC graphics card.

Abstract

A method is described for generating data for one or more objects residing in one or more scenes in a space defined by an axis system passing through an origin. The steps involve deriving a set of object data comprising coordinates, one or more of the coordinates corresponding to coordinates of object features. Object triangles are then defined based on the apexes formed from permutations of the coordinates of object features. One or more coordinates of the object data are then transformed based on the apexes of each object triangle, thereby forming a set of transformed object data. Data is then generated based on the set of transformed object data for one or more side of each object triangle of each object. This method enables a similar object, with an arbitrary position and orientation, to be recognised by an observer at an arbitrary position and orientation.

Figures

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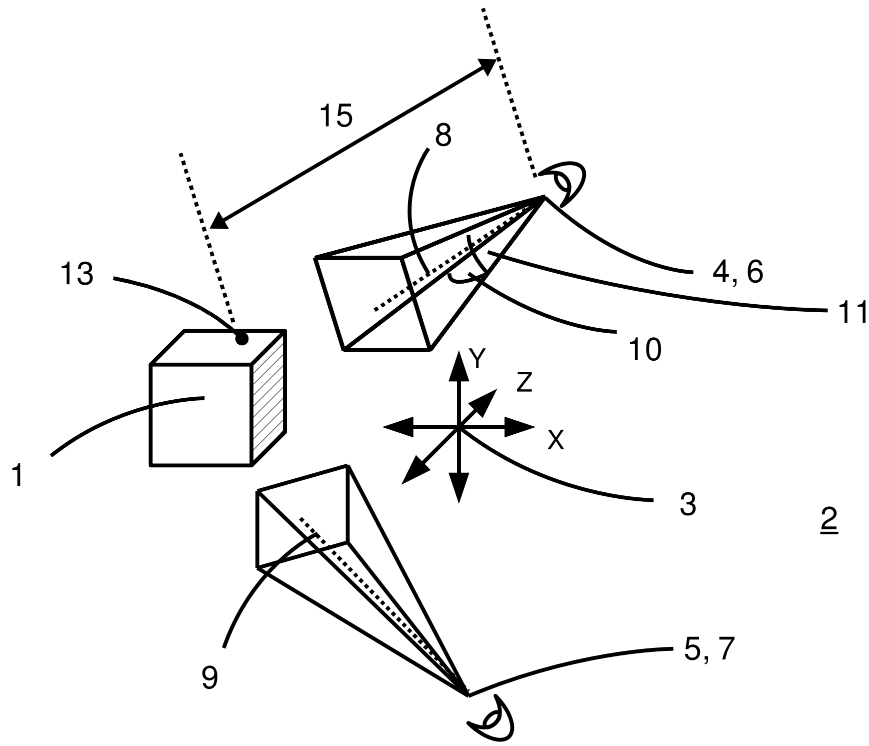


Fig 1.

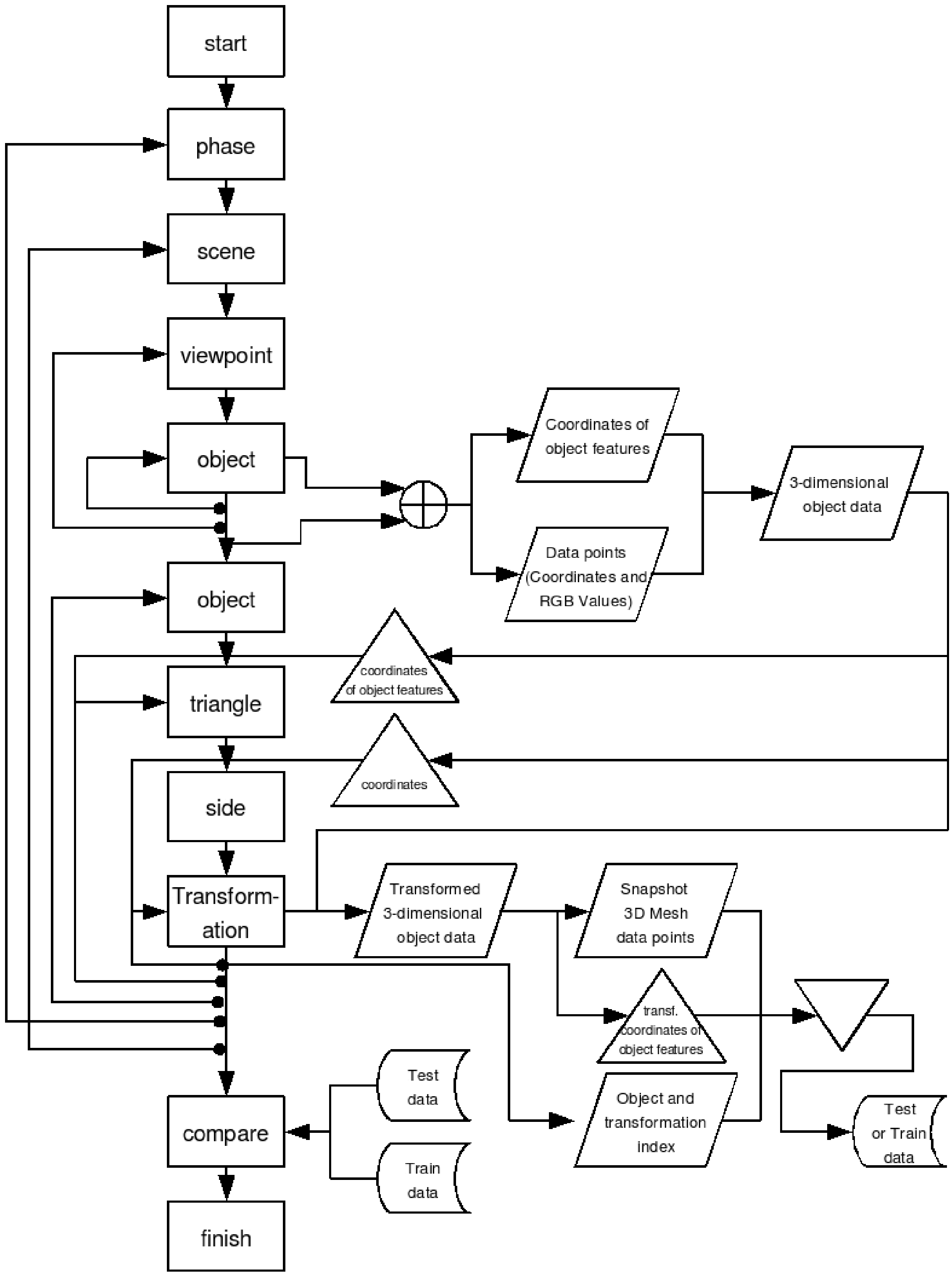

start
phase
scene
viewpoint
object
Coordinates of object features
Data points (Coordinates and RGB Values)
3-dimensional object data
object
coordinates of object features
triangle
coordinates
side
Transform-ation
Transformed 3-dimensional object data
Snapshot 3D Mesh data points
transf. coordinates of object features
Object and transformation index
Test or Train data
Test data
Train data
compare
finish

Fig 2.

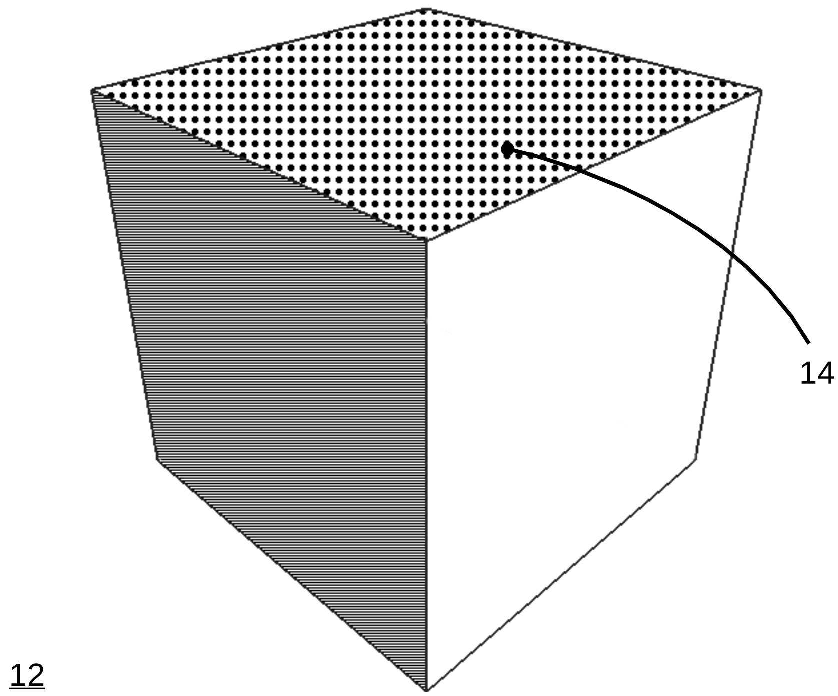


Fig 3.

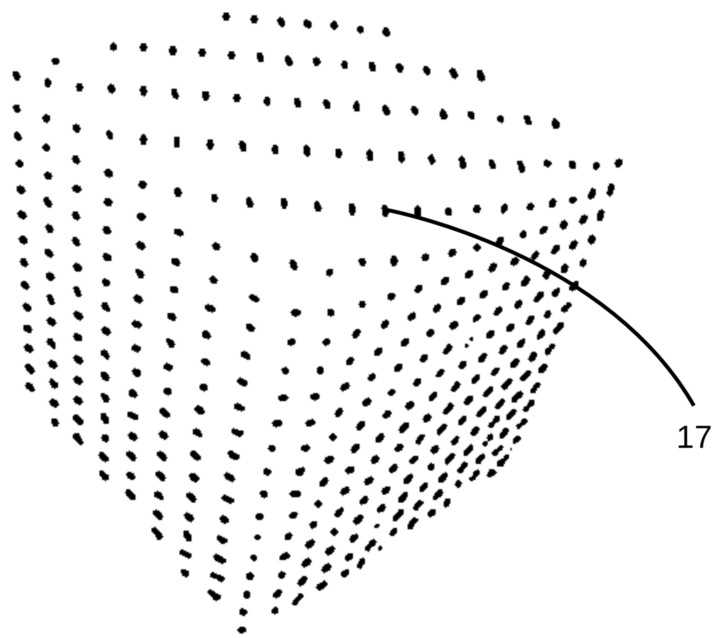


Fig 4.

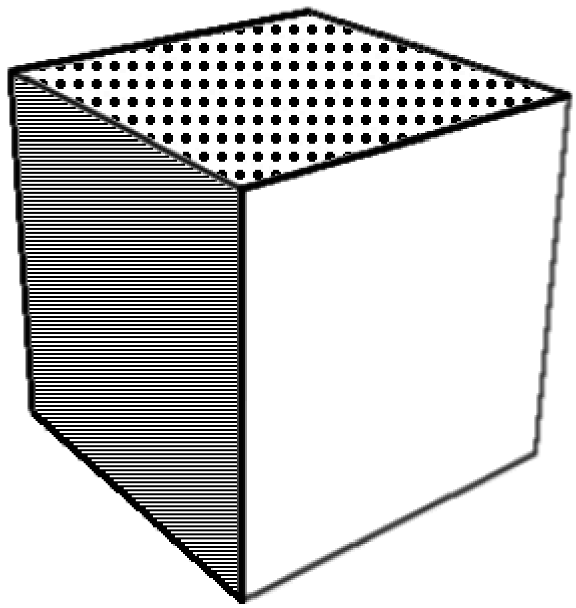


Fig 5.

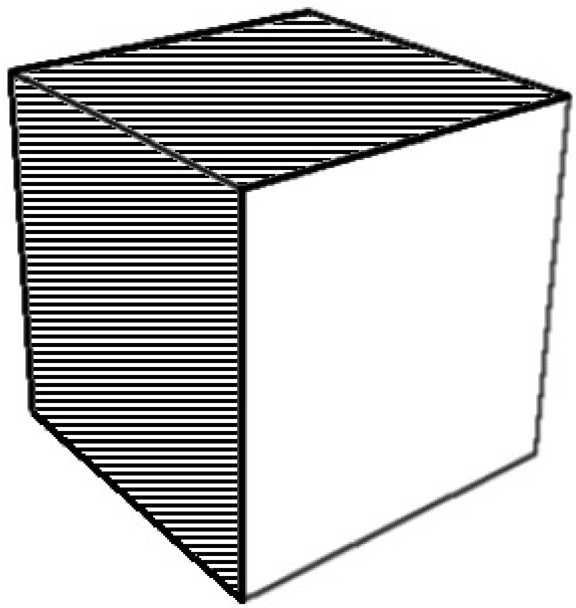


Fig 6.

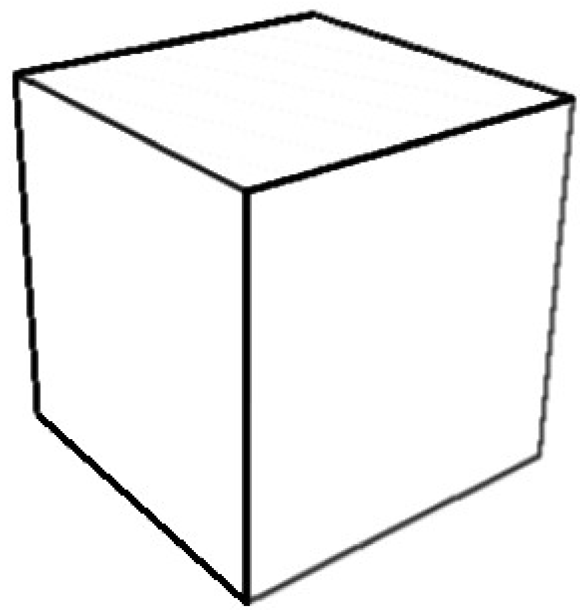


Fig 7.

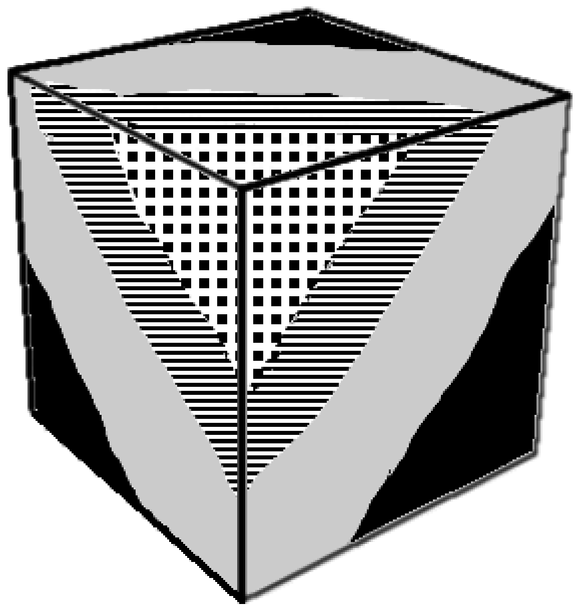


Fig 8.

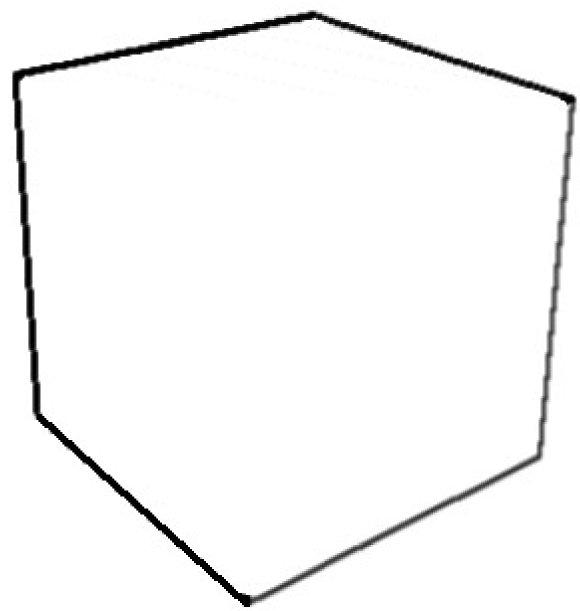


Fig 9.

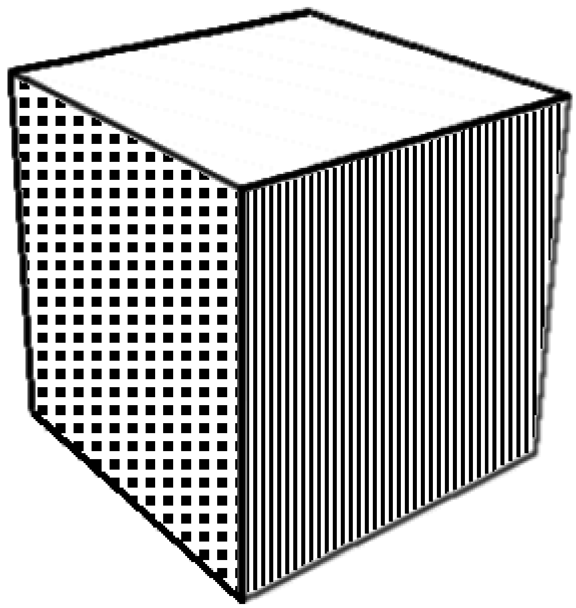
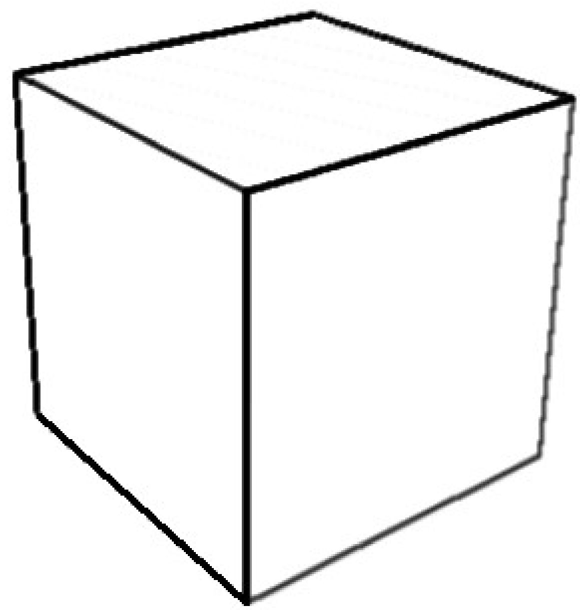


Fig 10.



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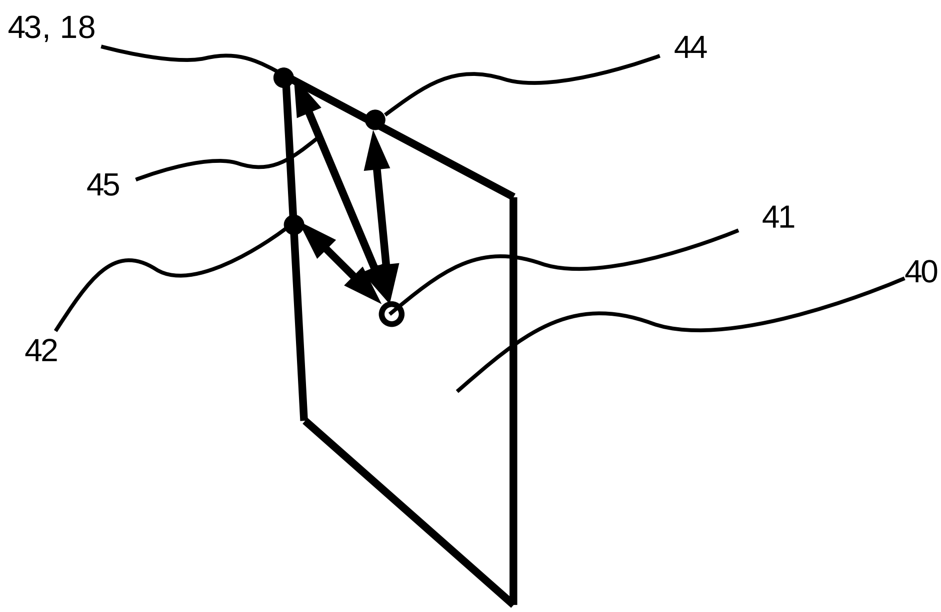

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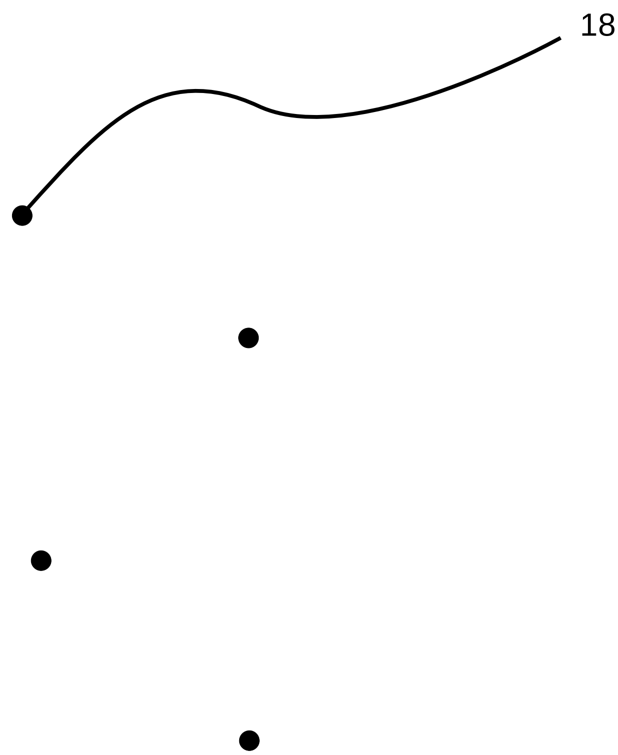

Fig 13.

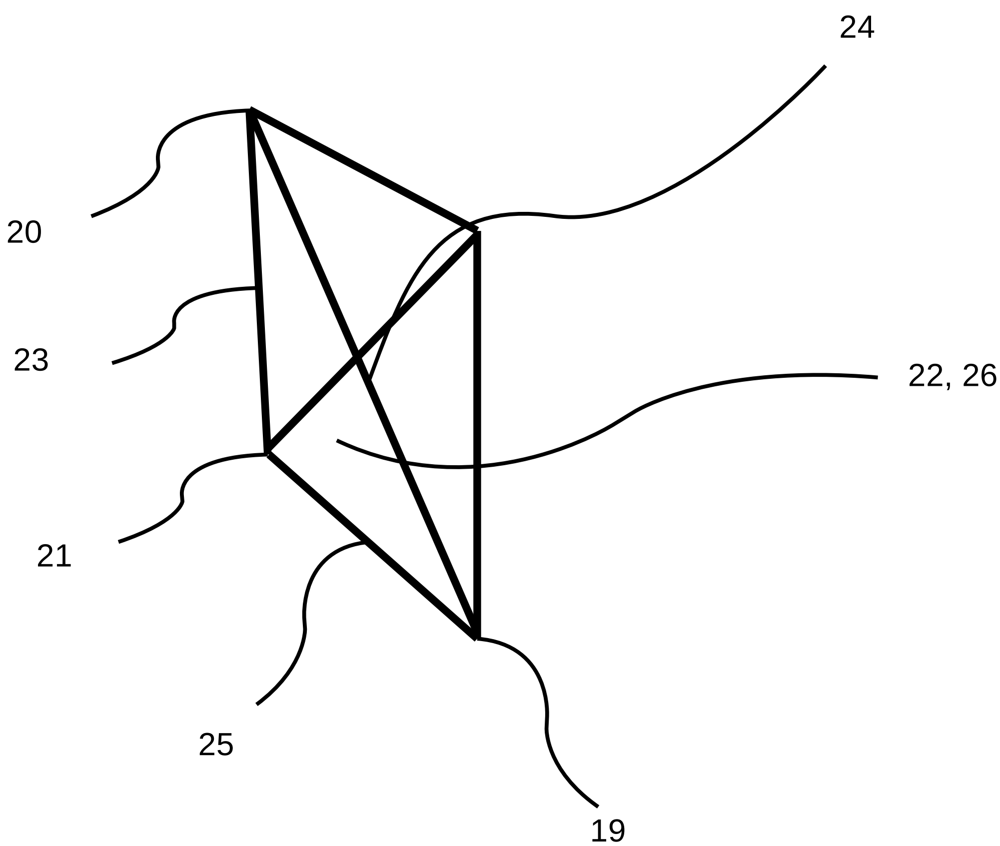

Fig 14.

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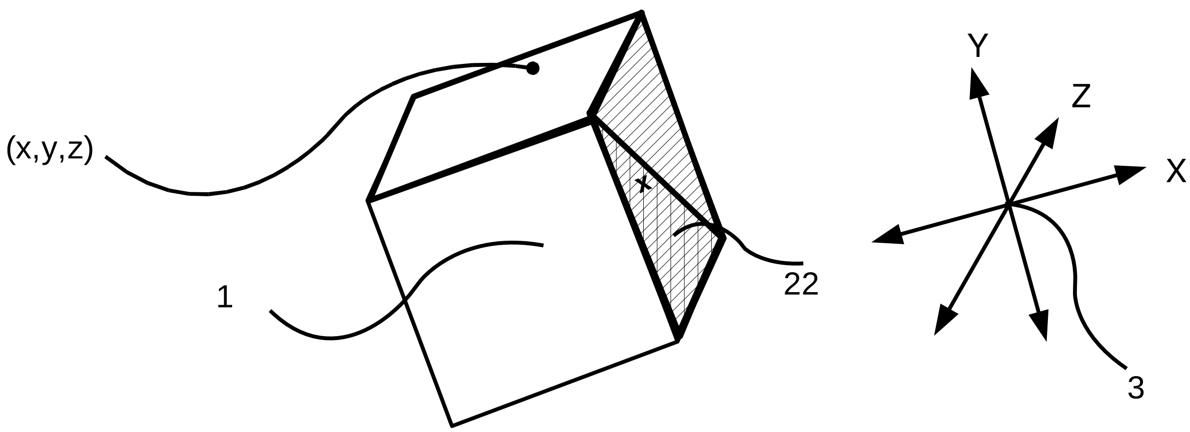


Fig 15.

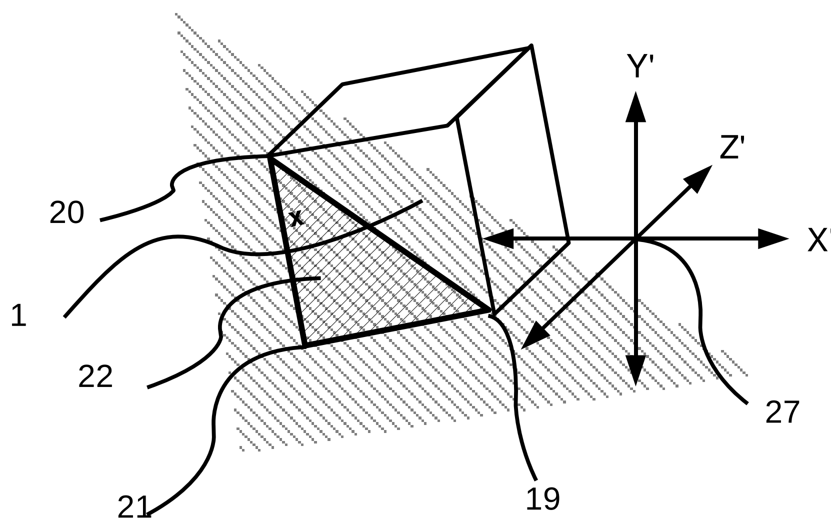


Fig 16.

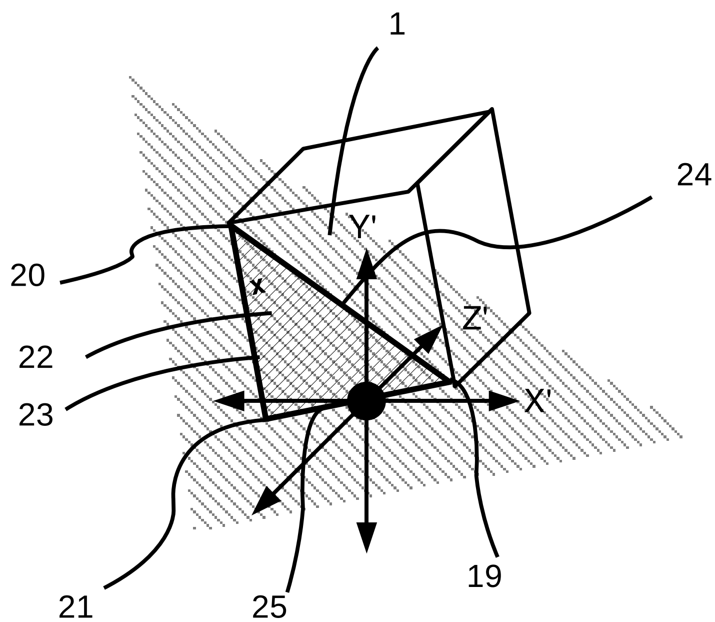


Fig 17.

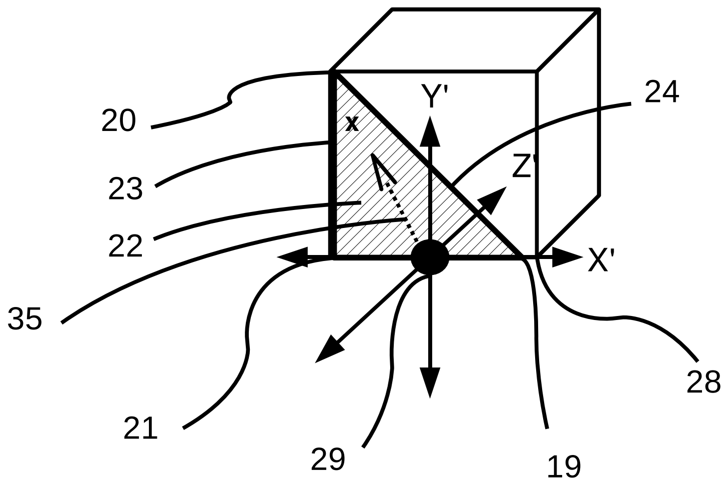
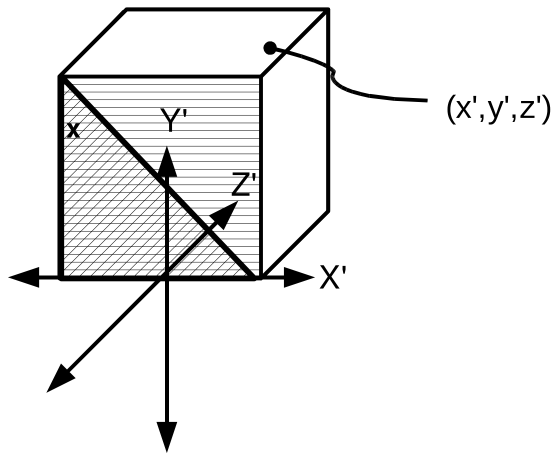


Fig 18.



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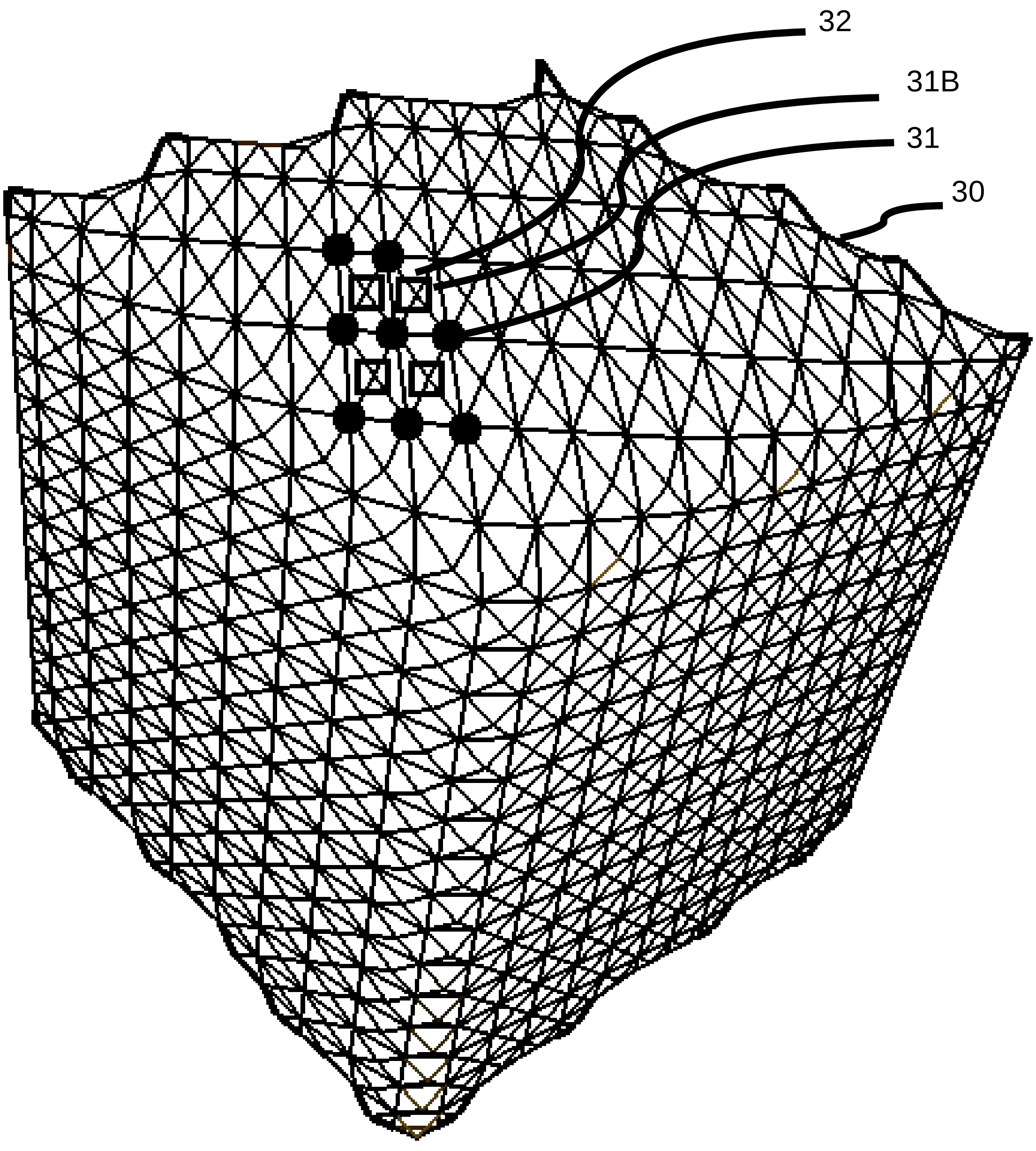
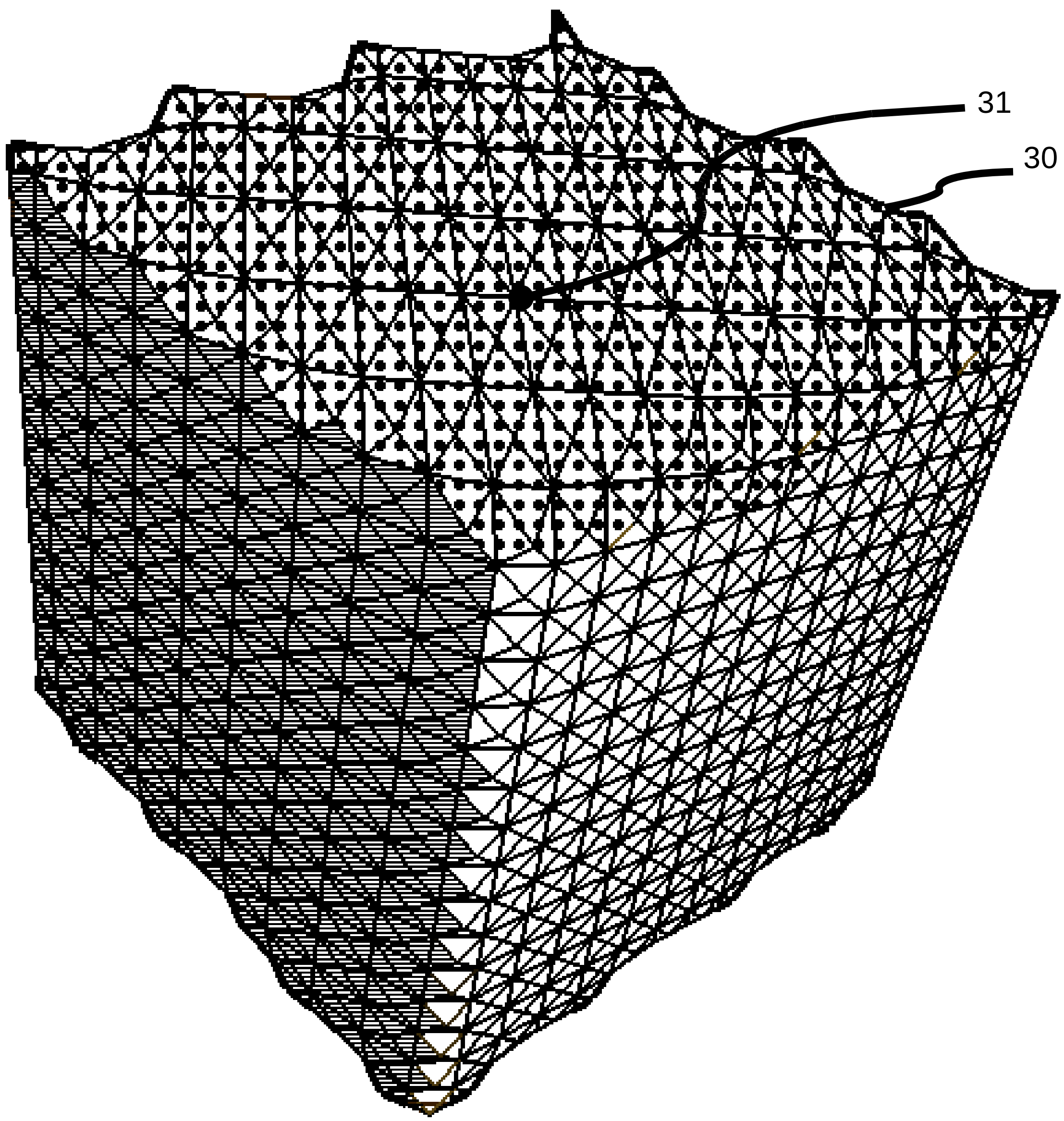


Fig 20.



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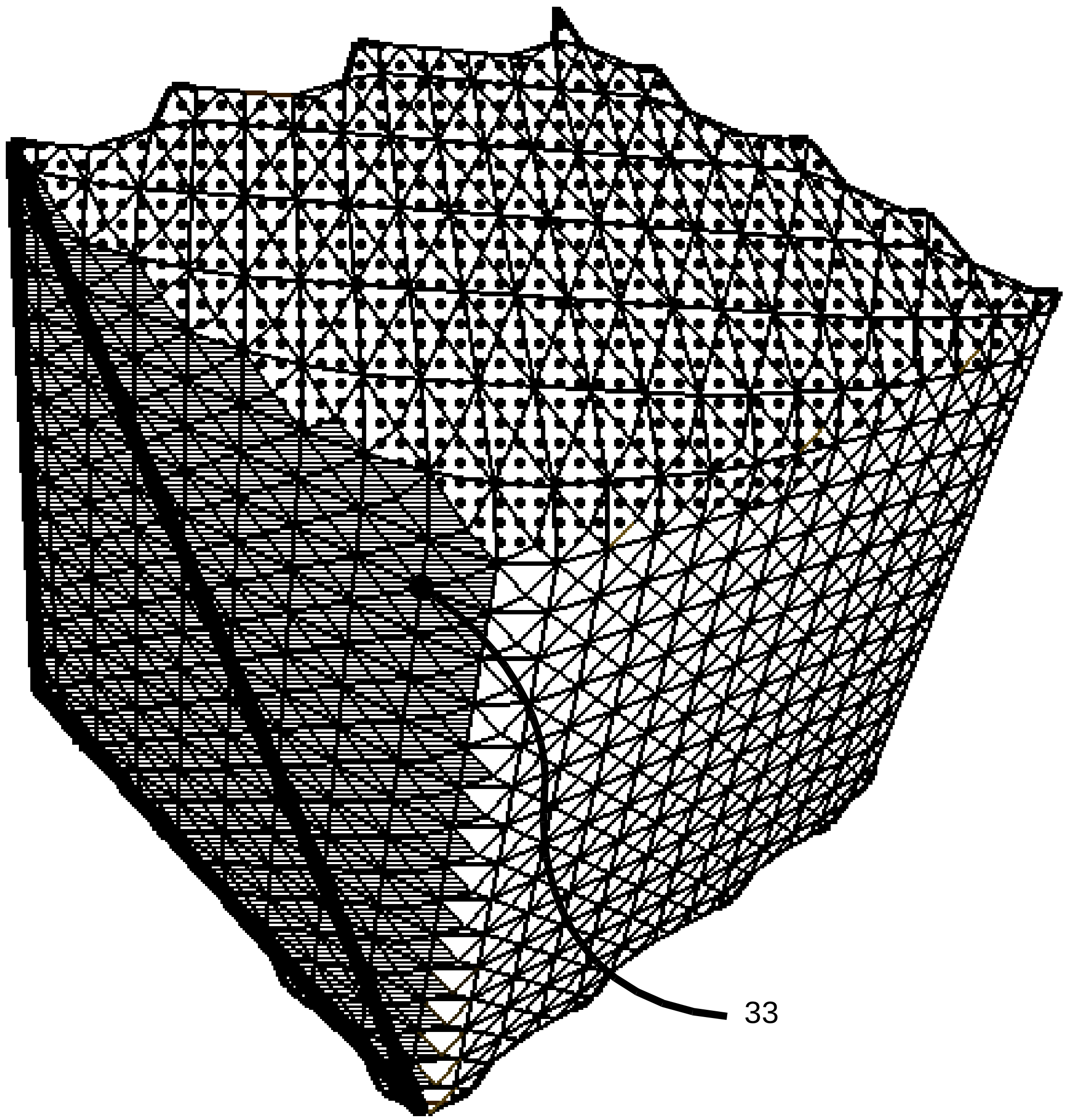

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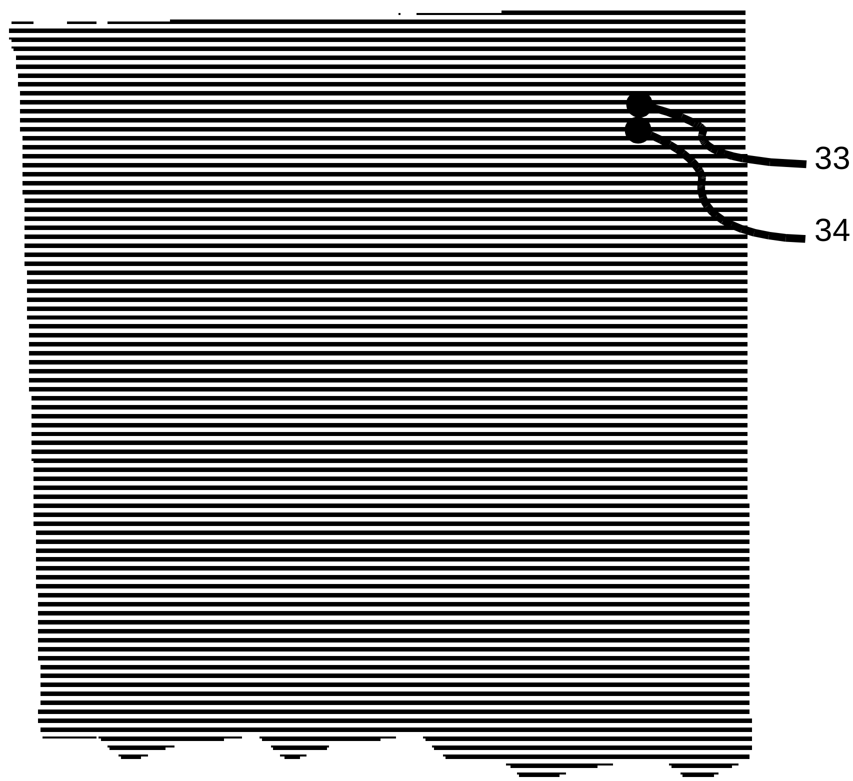

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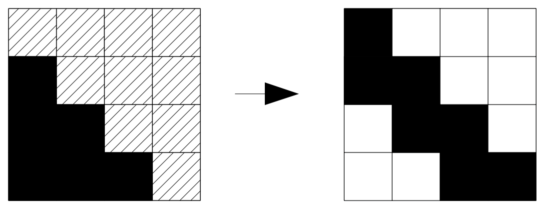

Fig. 24(a)

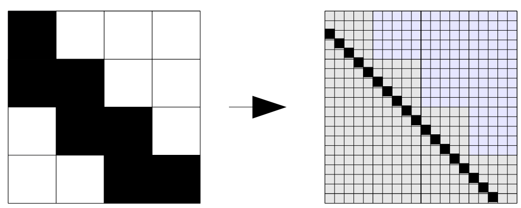

Fig. 24(b)

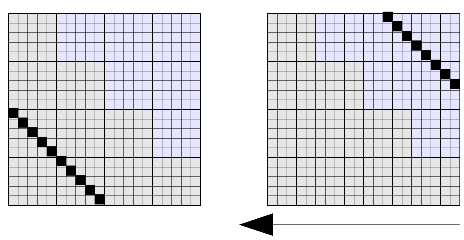

Fig. 24(c)

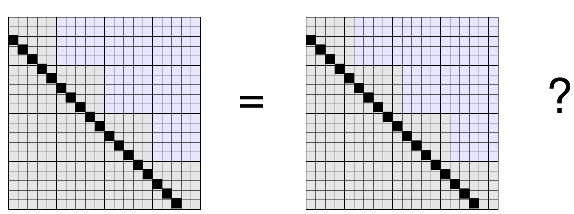

Fig. 24(d)

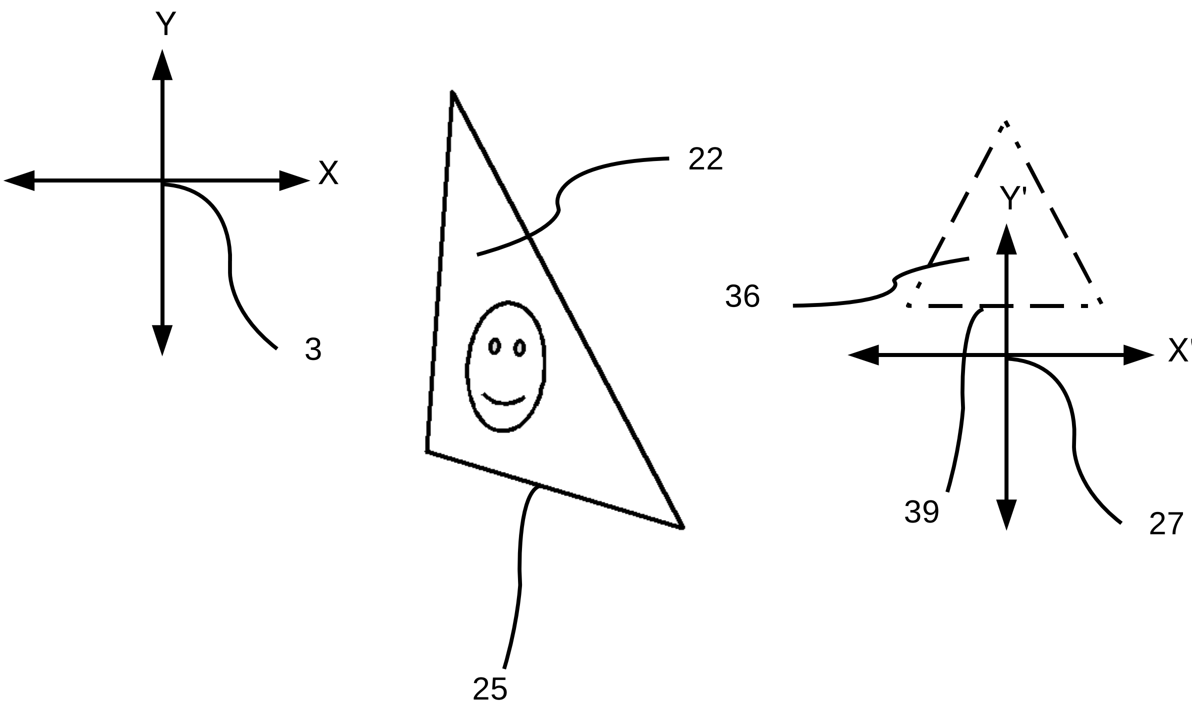

Fig 25.

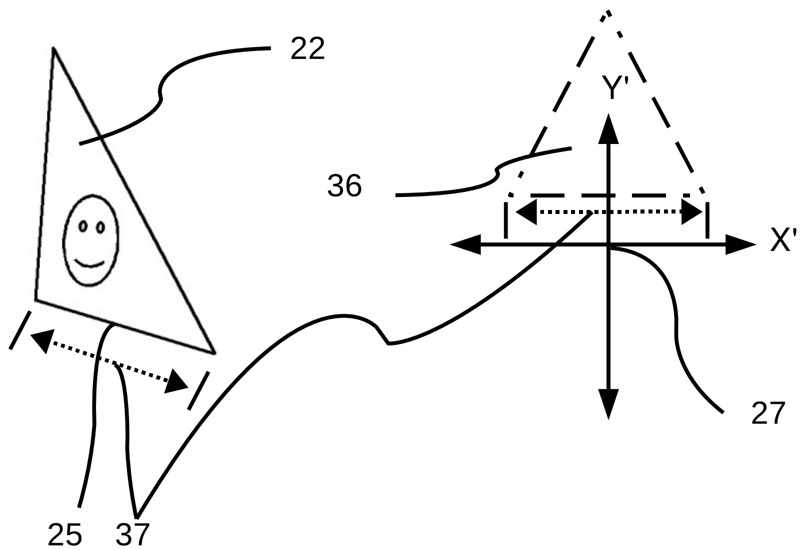

Fig 26.

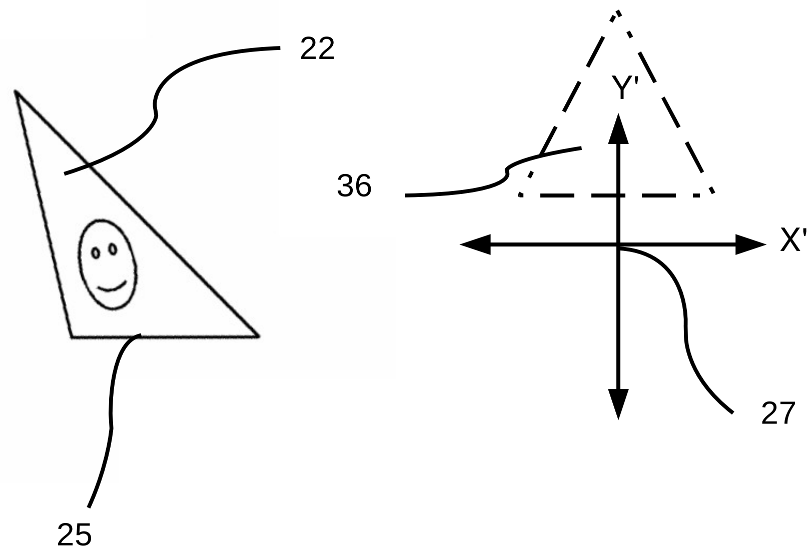

Fig 27.

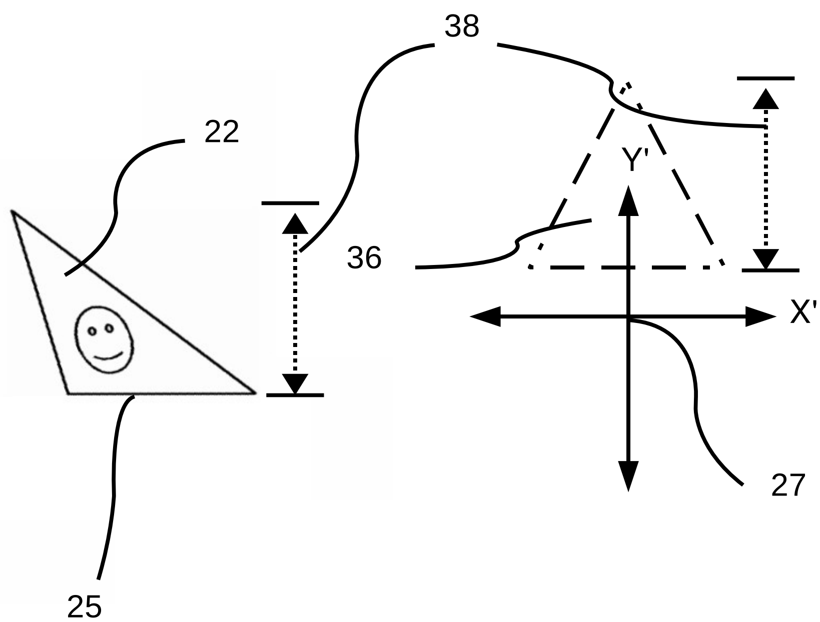

Fig 28.

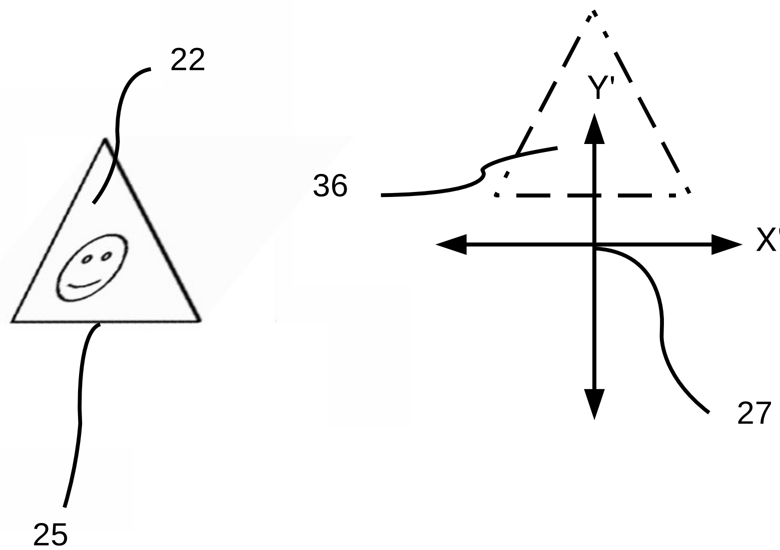

Fig 29.

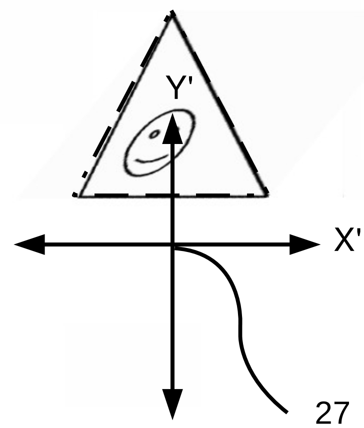

Fig 30.