(54) Title: CALCULATING THE DISTANCE BETWEEN GRAPHICAL OBJECTS
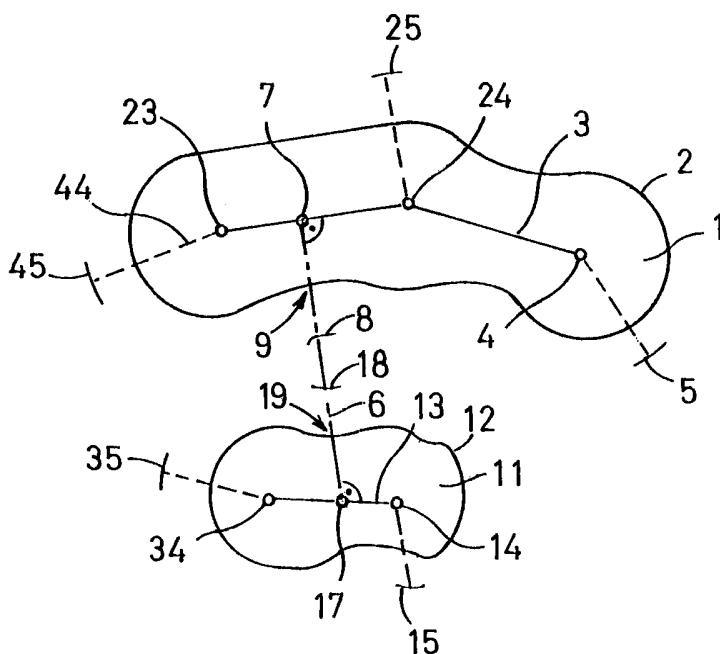
(57) Abstract: A method and representation system for graphical objects for fast calculation of interactions between said graphical objects being defined through a first closed geometrical curve is provided. Every object is represented through at least two nodes and neighboring nodes are connected through a skeleton line. A bounding object is attributed to every node defining sections in the neighborhood of every node wherein said sections forming a second closed geometrical curve being entirely inside or entirely outside of said first closed geometrical curve. Then the mean distance of a boundary object from a skeleton line or two points on the said skeleton line of both graphical objects in direction of the connection line of the minimum distance between said skeleton lines is calculated and the comparison is made between the sum of that values for both graphical objects on the connection line of the distance and said distance to device if a collision may happen.

CALCULATING THE DISTANCE BETWEEN GRAPHICAL OBJECTS

The invention relates to a system and method of image generation for graphical objects, especially to volume graphics and to a discrete object representation for at least two objects that allows accurate and fast calculations of interactions between said two graphical objects.

Within the prior art there are a multitude of approaches for the image generation for graphical objects, especially 3D-objects.

US 6,195,625 describes a method for simulating collisions of 3D-objects. Within this context the method of finite elements is mentioned which is one approach necessitating great calculation power.

US 6,131,097 discloses a method for authoring geometrical databases, especially in view of interactions between objects, wherein stiffness, friction and other properties of the objects and their surfaces may be incorporated. The approach used by US 6,131,097 are bounding boxes, to rule out distant objects. In a 3D-world this is a rather complicated approach when there are a multitude of objects and especially complicated objects.

US 6,040,835 describes a polygonal surface model to calculate the distance from a given point to said surface.

Based on the prior art the object of the invention is to provide a faster method to calculate the representation of graphical objects, especially in view of possible collisions between said objects.

For a method this object of the invention is achieved through the features of claim 1. For a system the features of claim 4 solve the underlying problem of the invention.

The method and representation system for graphical objects for fast calculation of interactions between said graphical objects is based on graphical objects being defined through a first closed or open geometrical curve. Every object is represented through at least two nodes and neighboring nodes are connected through a skeleton line. A bounding object is attributed to every node defining sections in the neighborhood of every node wherein said sections forming a second closed or open geometrical curve being entirely or partially inside or entirely or partially outside. Then the mean distance of a boundary object from a skeleton line of both graphical objects in direction of the connection line of the distance between said skeleton lines or two points on the said skeleton line is calculated and the comparison is made between the sum of that values for both graphical objects on the connection line of the distance and said distance to decide if a collision may happen.

It will be appreciated that the method is usable for the interaction between two 3D-objects and also between 3D- and 2D-objects and between two 2D-objects. Since the calculation reduces the calculation of boundary objects in a first step and surface objects in a second step to a one-dimensional or two-dimensional problem in each case the biggest reduction in calculation efforts can be found when two 3D-objects are in space.

These and other features of the invention will be better understood in relation of the detailed description in conjunction with the drawings, of which:

Fig. 1   shows a schematically cross-sectional view of two 3D-

objects one beside another,

Fig. 2   shows a schematically perspective view of a 2D-object with its boundary object,

Fig. 3   shows a schematically cross-sectional view of two 3D-objects, one object inside a hollow second object,

Fig. 4   shows a schematically cross-sectional view of the two 3D-objects of Fig. 3 using a different approach to reduce the number of necessary skeleton objects,

Fig. 5   shows a schematically cross-sectional view of two object, where one object has been cut open,

Fig. 6   shows a schematic view of a simple shaped object (e.g. tube) where the boundary bodies are used inside and outside to allow a fast and realistic collision as the intersection with the surface has not to be calculated,

Fig. 7   illustrates an approach with two arbitrary points on segments, wherein two intersections are tested to find the critical point on the surface, and

Fig. 8   illustrates a continuos search starting from an intersection on at surface until the critical point is found, which enables a fast calculation with neighborhood functions.

Fig. 1 shows a simple body 1 having an outer surface 2 and a line skeleton 3 and 23, connecting three nodes 4, 24 and 44. For simplicity, the drawing shows a 2D representation so that the surface 2 is a line (in the plane of representation). The three nodes 4, 24 and 44 are also all in the same plane. The method of the invention can be applied to such 2D representations. However, the method is very well suited for applications within a real 3D-environment. The representation of Fig. 1 can then be seen as the cross-section through the plane encompassing the skeleton lines 3, 23. In a more complicated case, no two skeleton lines 3, 23 are in the same plane and there are multitude of said nodes in different planes.

Fig. 1 further shows a second simple body 11 having an outer
surface 12 and a - one - skeleton line 13, connecting two nodes
14 and 34. It is noted that the two nodes 14, 34 are below and
above the plane of body 11. Therefore only one point of the
skeleton line 13 is in the same plane as skeleton lines 3 and 23
of first body 1.

Around every node 4, 24, 44 and 14, 34 of all bodies 1, 11 is
provided a bounding body 5, 25, 45 and 15, 35, respectively. For
simplicity reasons the bodies are supposed to be spheres and
only a radius is shown and receives the reference. Besides
spheres it is possible to use cubes or every other 3D body as
bounding body, so long as defined segments of the surfaces of
the bounding body encompass portions of the real surface 2, 12
of the objects 1, 11.

The method according to the invention then calculates the dis-
tance between all skeleton lines or two points on the skeleton
lines 3, 23 of one body with every skeleton line 12 of another
(every other) body 11. This calculation creates a point 7 on
skeleton line 23 between nodes 24 and 44. Point 7 divides the
length of skeleton line 23 in two portions X_{24} and X_{44}, wherein
$X_{24}+X_{44}$ equals to the distance between the two nodes 24 and 44.

The embodiment according to Fig. 1 uses spheres 25 and 45 as
bounding bodies around nodes 24 and 44 with radii R_{25} and R_{45}.
Then the relevant distance between the two skeleton lines or two
points on the skeleton lines 23 and 13 (i.e. the distance D_{7-17}
in space between points 7 and 17 can be found as the sum of two
distances calculated for every body 1 and 11, respectively.
These distances D_1 and D_{11}, in the drawings schematically shown
as 8 and 18, respectively, can be calculated from:

$$D_1 = (X_{24}*R_{45} + X_{44}*R_{25}) / (X_{24}+X_{44})$$

$$D_{11} = (X_{14}*R_{35} + X_{34}*R_{15}) / (X_{14}+X_{34})$$

It can be seen that in the case that the distance is in one node, e.g. node 44, than $X_{44} = 0$ and $D_1 = R_{45}$, e.g. the corresponding distance value from the bounding box around node 44.

If said distance between points 7 and 17, D_{7-17}, is greater than D_1+D_{11}, then this part of bodies 1 and 11 is not colliding and the next calculation can be performed, i.e. between the skeleton lines 3 and 13 of bodies 1 and 11.

It has to be noted that, when the bounding box is a complex structure, the relevant value R_{25} or R_{45} and R_{15} or R_{35} are scalar values which may be obtained from a matrix governing the form of the corresponding bounding box and these values may behave non continuous for different neighboring points on skeleton line 13 or 23.

If the above mentioned distance is smaller than the calculated sum than a second step of the method is performed for objects where the boundary boxes are not sufficient. For simple shaped objects (e.g. tubes) an inner boundary object can be defined for the whole object or parts of the object to avoid the second step. The model of the graphical representation of the bodies 1 and 11 encompass surface elements 2 and 12. Although the second step has not to be performed for the position of the bodies 1 and 11 in Fig. 1 the principle can be effectively demonstrated. The second method step provides the calculation of the points 9 and 19 within the surface 2 and 12, respectively, being on the line 6 of the shortest distance in distances D_{7-9} and D_{17-19} from

points 7 and 17, respectively. Only in the case that D_{7-9} + D_{17-19} is greater than D_{7-17} a collision has occurred and some supplemental action has to be taken, depending on the kind of elements colliding (stiffness, sharpness, etc…).

This method effectively reduces the calculations of distances between a multitude of more or less complex 3D bounding boxes through a first test necessitating only a scalar calculation and comparison for distances between two points in space, and, only if this proves successful (i.e. collision possible), a second test has to be performed calculating the distances between two further points which are easily derived on the basis of the first test. Therefore two complex 3D-calculations are replaced by two simpler 1D-calculations. The embodiment shown in Fig. 1 relates to global movement.

It is furthermore possible to use the method for local deformations.

In the case of collision, it is possible to use one or both intermediate points 7 and 17 as new nodes and restarting the calculations of the method with the skeleton line 23 being replaced through two skeleton lines (between node 44 and new node 7, and new node 7 and node 24), enabling that one part of one body is gliding and pivoting, e.g. falling, around the other body.

It is also possible to define that one surface, e.g. all points 19 within body 11, is stiff and is not to be deformed. This can be used within representation of medical procedures for scissors or an endoscope etc. . Within simulation of impact of an object (e.g. a stone) into a car this may be used for such an object as a stone. Then, within the global picture, the relevant nodes 24 and 44 or 14 and 34 are displaced.

A body can also be defined as flexible. This can be used for an organ represented within medical procedures or above mentioned car hurt by a stone. Then the point 9 or 19 is able to be "pushed" in direction of line 6 towards the skeleton line 23 or 13 without moving the inner skeleton nodes 24 and 44 or 14 and 34. This can be governed through a resistance factor growing with reduced distance to the skeleton line 23 or 13. This simple procedure has the advantage that the direction of deformation is always correct, i.e. in the direction of the impact, e.g. the shortest distance between points of the skeleton links.

Fig. 2 shows schematically the use of the method within a 2D-object 21. Such an object 21 may be a cloth covering a 3D-body within a graphical representation or a hernia net within surgical representations, interacting with another 2D-object or a 3D-object as an endoscopic instrument to virtually place such a 2D-surface. Usually 2D-objects 21 are demonstrated through triangles 50, 51 and 52. However, also other geometrical forms of representations are possible as different polygons. Triangle 50 comprises a 3D-environment 53 having an upper 3D-part 54, a lower 3D-part 55 and a sideways extending part 56. This is just another more complicated bounding body than the spheres of Fig. 1. Here it is possible to define the distance of the surface 50 of 2D-body 21 to another body, either another surface or a skeleton line. This shortest distance 16 is represented through an arrow starting from a point 27. As in the method described within Fig. 1 the intersection point 28 of the bounding body 53 with the shortest distance line 16 is calculated and only in the case that the sum of the distance from point 27 to intersection point 28, i.e. D_{27-28}, and e.g. D_{11} is smaller than the length of line 16 the second step is entered wherein the surface structure, i.e. line structure, of the bodies 21 and 1 or 11 is cal-

culated, to decide, if collision occurs.

Fig. 3 shows a partly very schematically representation of the
application of the method according to Fig. 1 and 2 to the
graphical representation of an body 31 inside another body 41 or
a hollow body 41 having a second body 31 inside. A typical
situation for the need of such a representation for the first
mentioned category is an object within an organ and the second
mentioned category relates to an body opening 31 of a human or
an animal as the esophagus or the colon or the interior of a
hollow organ as the stomach, wherein the second body 41 is an
endoscope or a foreign object. As can be seen from Fig. 3 hollow
body 31 than necessitates an important number of nodes 64 which
gives rise to an important number of skeleton lines to be com-
pared against the lines 3 and 23 of body 41. The number of cal-
culations according to the method of the invention can be re-
duced significantly using a slightly different method shown in
Fig. 4. The difference is that the nodes 64 for the body 31 are
positioned inside the hollow space and therefore the first cate-
gory (object within an object) is now treated in an identical
way then the second category (object within hollow object).

In order to evaluate the risk of collision between objects 31
and 41 it is not the shortest distance between skeleton lines 13
and 63 but the greatest "shortest distance" between points on
the skeleton line 13 of the smaller body 41 and the skeleton
line 63 of the hollow body 31 (or bigger body).Said distance can
always be found as the normal from the end nodes 24 or 44 of the
skeleton line 13 towards the skeleton line 63. Then the distance
18 from point 44 in the direction away from skeleton line 63 is
calculated as in the embodiment described in connection with
Fig. 1. In view of body 31 the bounding body is an inner bound-
ing body with two parameters for point 67 on skeleton line 63.

With X_{64} as distance between points 64 and 67 and $X_{64'}$ as distance between points 64' and 67, and R_{64} as bounding body value for point 64 and $R_{64'}$ as bounding body value for point 64' the distance for body 31, shown as reference 68 is calculated as:

$$D_{31} = (X_{64}*R_{64'} + X_{34'}*R_{64}) / (X_{64}+X_{64'})$$

Then a collision of the inner body 41 with the hollow body 31 (equivalent to the exit of body 41 out of body 31) is to be tested when D_{31} is smaller than the sum of distance between points 67 and 44 D_{67-44} and D_1. In this case the second calculation for points 19 and 69 has to be performed as in the first embodiment along and using the line 66.

It has to be noted that, although all embodiments are showing two distinct bodies, it is possible that the calculation has to be performed between different sections of the same body in case that said body is so flexible that two sections of it may interact. An example for such a case of one-body-interaction is the graphical representation of the small intestine. Therefore the wording two graphical objects has also the meaning two parts or sections of one body spaced apart within one body.

It is clear that the method according to the invention can be modified through a number of parameters without leaving the scope of protection defined through the enclosed claims.

Claims

1.   An method of image generation for graphical objects (1, 11, 21, 31, 41, 61) for fast calculation of interactions between said graphical objects (1, 11, 21, 31, 41, 61) being defined through a first closed or open geometrical curve (2, 12, 62), wherein every object (1, 11, 21, 31, 41, 61) is represented through at least one node (4, 14, 24, 34, 44, 64, 64'), neighboring nodes (4 and 24, 24 and 44, 14 and 34, 64 and 64') being connected through a skeleton line (3, 23, 13, 63 respectively), wherein a bounding object (5, 15, 35, 45) is attributed to every node (4, 14, 24, 34, 44, 64, 64') defining sections in the neighborhood of every node wherein said sections forming a second closed or open geometrical curve being entirely or partially inside or entirely or partially outside of said first closed geometrical curve, said method comprising the steps of

in the case that the second closed or open geometrical curve being outside of said first closed or open geometrical curve for both graphical objects:

a)   calculating the distance (D_{7-17}) between two skeleton lines or two points on the said skeleton lines or nodes of the skeleton of two graphical objects, creating a point (7; 17) on each skeleton line (23; 13) between and including the corresponding nodes (24, 44; 14, 34) dividing the length of each skeleton line (23; 13) in two portions,

b)   calculating the dimension (R_{15}, R_{25}, R_{35}, R_{45}) of the bounding object in direction of the connection line of the distance (D_{7-17}) for every node,

c)   calculating the dimension (D_1, D_{11}) of the bounding object in direction of said connection line at said point for every object as proportional to the relative distance of said point to the neighboring nodes,

d)   comparing the sum (D_1+D_{11}) of said dimensions of the bounding objects of both graphical objects with said distance (D_{7-17}), and

e)   in the case that said distance (D_{7-17}) is greater than said sum (D_1+D_{11}) of said dimensions of the bounding objects acknowledging that this part of the graphical objects is not colliding and restarting at step a) with further skeleton lines, and in the case that said minimum distance (D_{7-17}) is smaller or equal said sum (D_1+D_{11}) performing a further collision detecting step; whereas in the case that the second closed or open geometrical curve being inside of said first closed or open geometrical curve for a first graphical object (31):

a)   calculating the distance (D_{7-17}) between a skeleton line (63) or points on skeleton line or nodes of the skeleton of the first graphical object (31) and a node (4, 24, 44) of the second graphical object (41), creating a point (67) on the skeleton line (63) between and including the corresponding nodes (64, 64') dividing the length of the skeleton line (63) in two portions,

b)   calculating the dimension (R_{35}) of the bounding object in direction of the connection line of the distance (66, D_{67-17}) for every node (44; 64, 64'),

c)   calculating the dimension of the bounding object in direction of said connection line at said point of the first graphical object (31) as proportional to the relative distance of said point to the neighboring nodes (64, 64'),

d)   comparing the sum of said distance (D_{67-17}) plus the dimension of the bounding object for the node of the second graphical object (41) with the dimension of the bounding object of the first graphical object (31), and

e)   in the case that said sum is smaller than the dimension of the bounding object of the first graphical object (31), acknowl-

edging that this part of the graphical objects is not colliding and restarting at step a) with further skeleton lines and nodes, and in the case that said sum is greater than the dimension of the bounding object of the first graphical object (31), performing a further collision detecting step.

2.   The method according to claim 1, wherein the objects are 2D or 3D objects and in that the geometrical curves are surfaces or lines.

3.   The method according to claim 1, wherein the further collision detecting step comprises the step of
-    calculating the intersection point of said geometrical curves of first and second graphical object on the line (6) of the distance, whereas it is assumed that a collision has occurred if the sum of the distances between said intersection points and the relating point on the skeleton line or node is greater than the distance between the relating points on the skeleton line or node.

4.   A representation system for graphical objects for fast calculation of interactions between said graphical objects being defined through a first closed or open geometrical curve, wherein every object is represented through at least one node, neighboring nodes being connected through a skeleton line, wherein a bounding object is attributed to every node defining sections in the neighborhood of every node wherein said sections forming a second closed geometrical curve being inside or outside of said first closed geometrical curve, with means for calculating the mean distance of a boundary object from a skeleton line of both graphical objects in direction of the connection line of the distance between said skeleton lines or two points on the said skeleton line and for making the comparison between

the sum of that values for both graphical objects on the connection line of the distance and said relevant distance.

5.   The system according to claim 4, further comprising means performing a further collision detecting step calculating the intersection point of said geometrical curves of first and second graphical object on the line of the shortest distance and making the decision that a collision has occurred if the sum of the distances between said intersection points and the relating point on the skeleton line or node is greater than the distance between the relating points on the skeleton line or node.
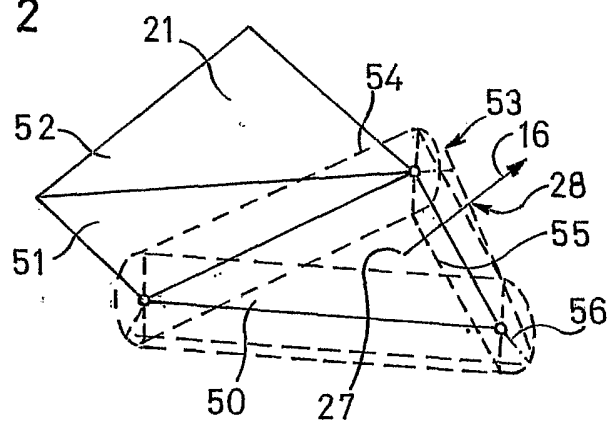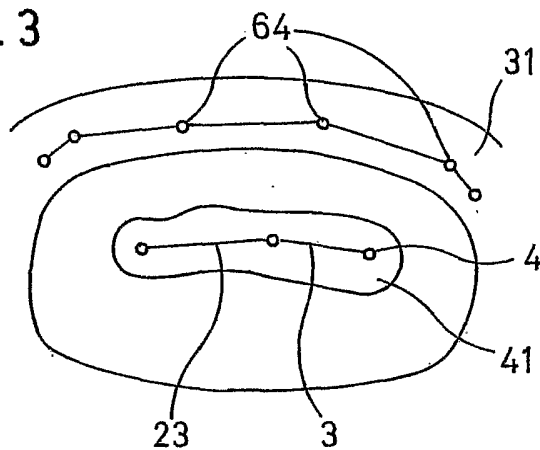
Fig. 1
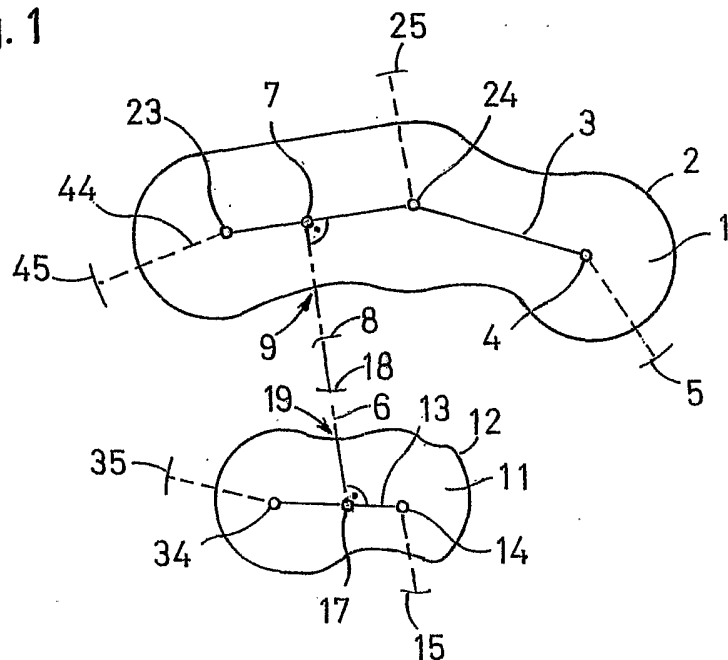
Fig. 2

Fig. 3

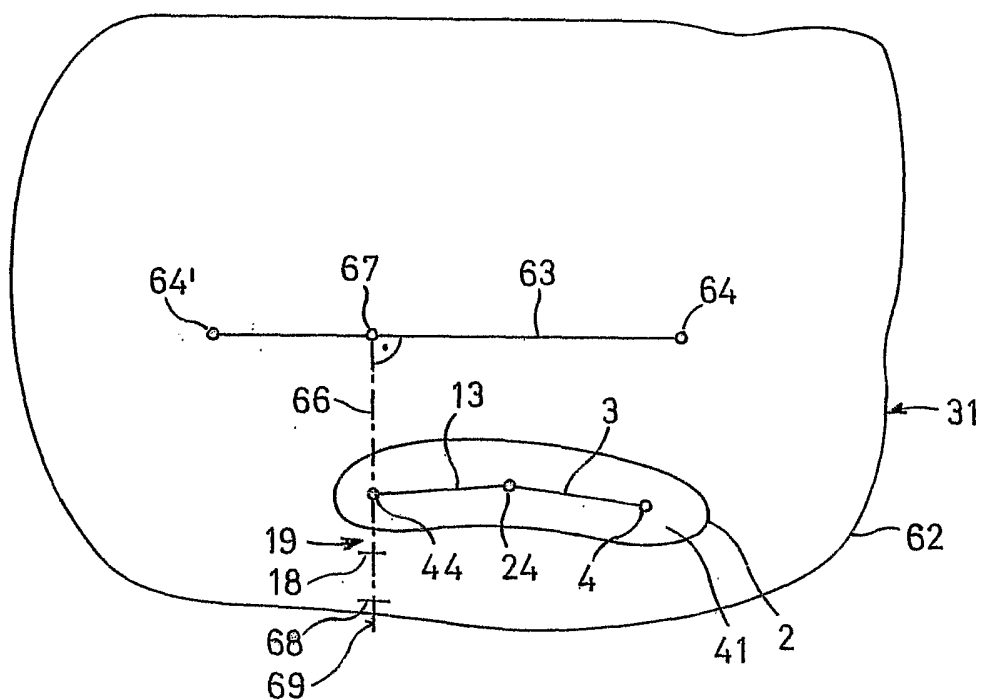Fig. 4   2 / 3

Fig. 5

Fig. 6

3 / 3
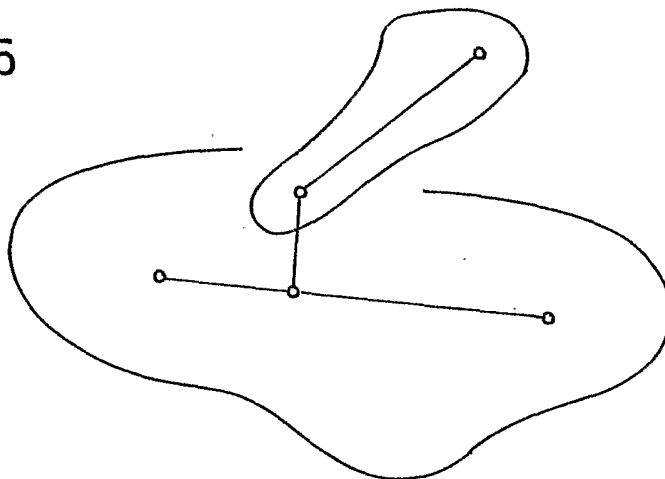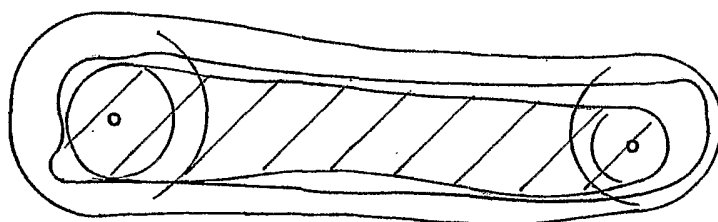
Fig. 7

Fig. 8

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   G06T17/10   G06T15/00

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7   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)

INSPEC, WPI Data, 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	GUEZIEC A: "MESHSWEEPER: DYNAMIC POINT-TO-POLYGONAL-MESH DISTANCE AND APPLICATIONS" IEEE TRANSACTIONS ON VISUALIZATION AND COMPUTER GRAPHICS, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 7, no. 1, 1 January 2001 (2001-01-01), pages 47-61, XP001005115 ISSN: 1077-2626 page 47 -page 51 figures 4,6,7 ___ -/--	1-5

[X] Further documents are listed in the continuation of box C.   [X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not
   considered to be of particular relevance

"E" earlier document but published on or after the international
   filing date

"L" document which may throw doubts on priority claim(s) or
   which is cited to establish the publication date of another
   citation or other special reason (as specified)

"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 docu-
   ments, 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
21 February 2002	04/03/2002

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, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Meinl, W

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	SU C-J ET AL: "A new collision detection method for CSG-represented objects in virtual manufacturing" COMPUTERS IN INDUSTRY, ELSEVIER SCIENCE PUBLISHERS. AMSTERDAM, NL, vol. 40, no. 1, September 1999 (1999-09), pages 1-13, XP004178446 ISSN: 0166-3615 page 1 -page 6 figure 4	1-5
A	US 6 131 097 A (JACOBUS CHARLES J ET AL) 10 October 2000 (2000-10-10) cited in the application abstract figures 4,9,11	

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
US 6131097	A	10-10-2000	US	5629594 A	13-05-1997
			US	5459382 A	17-10-1995
			US	5389865 A	14-02-1995
			US	5831408 A	03-11-1998
			US	6104158 A	15-08-2000
			US	5844392 A	01-12-1998
			US	5872438 A	16-02-1999
			US	5769640 A	23-06-1998