(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(54) Title: METHOD FOR ANIMATING CHARACTERS, WITH COLLISION AVOIDANCE BASED ON TRACING INFORMATION

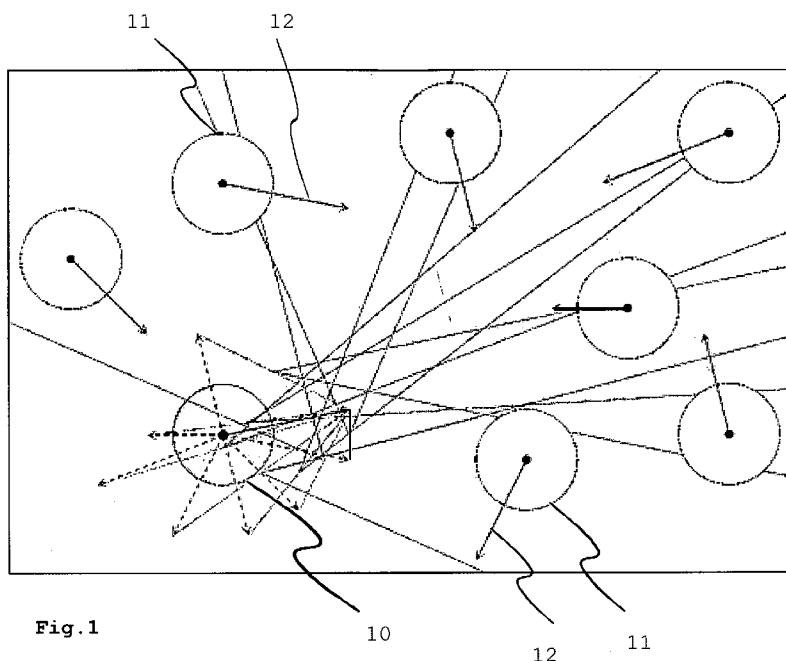(57) Abstract: A method for determining a moving direction or moving velocity for a character in a group comprises reading tracing information from a cell in a terrain map on which the character is located, determining if collision avoidance is needed, and if a collision avoiding manoeuvre is necessary then updating the tracing information in the current terrain cell.

Fig.1

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METHOD FOR ANIMATING CHARACTERS, WITH COLLISION AVOIDANCE
BASED ON TRACING INFORMATION

This invention relates to a method for animating characters,
and in particular for animating large groups of characters,
also called crowds.

Background of the invention

Crowd simulation is widely used in games, movies, urban
planning and emergency evacuation simulation. A group of
characters, or crowd, is a collection of people/characters
that stick together, have the same goal and behave similarly.
Group behaviour is very common in our daily life and has
been widely studied. If there is strong grouping behaviour
in a crowd, it is known to simulate it by first planning the
path for each group as a whole, and then planning the
activities of each character within the group. One of the
most important aspects in crowd simulation is collision
avoiding, especially among virtual characters (avatars). In
order to make the characters look natural, each character
should behave individually, and particularly it should move
on its own way in a given terrain. The terrain is
represented by a terrain map or roadmap. One problem is that
the simulation complexity is high, since each character
inside the group undergoes an evaluation of its individual
position and situation, for example the "potential field"
manoeuvre: each character inside the group moves according
to its individual position and environment. In the
"potential field" manoeuvre, each character's position and
environment is evaluated from scratch for deciding the next
step.

Usually, complex calculation on velocity adjustment is
performed, as e.g. in "Reciprocal velocity obstacles for

real-time multi-agent navigation", J. van den Berg, M. Lin,
D. Manocha, IEEE International Conference on Robotics and
Automation, 2008.

5   Summary of the invention
According to the present invention, information about at
least the computed new velocity will then be stored in cells
of the terrain map or roadmap, and it will influence at
least the next character that enters the cell. Preferably,
10   the roadmap influences individual behaviour of at least the
next character, not the group behaviour in general. Other
than in a known technique of grid searching, the information
is not related to fixed terrain obstacles, as used for path
planning. Instead, the information stored in the terrain map
15   is only an intermediate result, and it is used as a
guideline for deciding based on current circumstances for at
least the next character.

In one aspect, the invention deals with how to size the grid
20   cells, how to use it for collision avoiding, how to organize
tracing information, and how to judge the effectiveness of
the information.

In one embodiment of the invention, a device for determining
25   for a character in a group at least one of a moving
direction and a moving velocity, comprising a memory for
storing cells of a terrain map, first data read means for
reading tracing information from a current cell in a terrain
map on which the character is located, a first collision
30   detector for determining, based on the tracing information
from the first data read means, whether or not collision
avoidance is needed, and for notifying the determining
result, a first position calculator for advancing the
character according to its previous direction and previous

velocity if the first calculator notifies that collision
avoidance is not needed, a first processor for searching, if
the first calculator notifies that collision avoidance is
needed, for at least one of a matching direction and
5   velocity, a second processor for computing a time-to-
collision based on the found matching direction and/or
velocity, a comparator for comparing the computed time-to-
collision with a predetermined range, and a second position
calculator for advancing the character according to the
10   found matching direction and/or velocity, and for performing
a collision avoiding manoeuvre and updating the tracing
information in the current terrain cell if no matching
direction and/or velocity is found, or if the time-to-
collision is outside the predetermined range.

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For example, a given terrain is cut into cells of a
determined size. The size is determined according to various
parameters, e.g. typical velocity (see below). For a
character that enters a terrain cell, the entry direction is
20   determined (e.g. one of north N, east E, south S, west W, or
one of north N, north-east NE, east E, south-east SE etc.),
and it is determined what the direction and/or velocity
decision was for previous characters that entered from the
same direction. Then it may be checked if certain
25   preconditions that led to the decision are still valid.

Reciprocal Velocity Obstacle (RVO) as described in "Real-
time rendering of densely populated urban environments", F.
Tecchia, Y. Chrysanthou, Proceedings of the Eurographics
30   Workshop on Rendering Techniques, 2000, is a new technique
dealing with collision avoidance. In the case of a two-
character scenario, there is an RVO area (or range) for each
of the characters on the velocity plane which indicates the
velocities that the characters ought not to choose, so that

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collisions can be prevented. If a character chooses any velocity out of the RVO area, it is guaranteed to avoid the collision with the other character. The RVO technique also assumes that each of the characters adopts the same strategy
5   to avoid collision. In other words, the characters share the responsibility and take action accordingly to avoid any collision.

Brief description of the drawings
10 Exemplary embodiments of the invention are described with reference to the accompanying drawings, which show in

Fig.1 a multi-character scenario Reciprocal Velocity
        Obstacle;

Fig.2 steps of a simulation method;

15 Fig.3 a portion of a terrain grid;

Fig.4 a grid portion and tracing information; and

Fig.5 a block diagram of a device for determining at least
        one of a moving direction and a moving velocity for a
        character in a group.

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Detailed description of the invention

Fig.1 shows a multi-character scenario RVO. In Fig.1, one character 10 should choose a velocity which lies out of the combination of the RVOs of all the neighbouring characters.
25 The neighbouring characters 11 have individual moving directions and speeds 12. However, in a very crowded situation, this velocity may not exist. Thus, for proceeding with the simulation, we still have to choose a velocity for the character. Therefore we choose the velocity with the
30 least "penalty". A typical penalty function for character i is:

$$penalty_i(\mathbf{v}_i') = w_i \frac{1}{tc_i(\mathbf{v}_i')} + \|\mathbf{v}_i^{\mathrm{pref}} - \mathbf{v}_i'\|$$

                                                                                    (1)

In eq.(1), V_i' is the new velocity; V_i^{pref} is the preference velocity; $tc_i(V_i')$ is the estimated time to collision; w_i is the weight to balance between time to collision and velocity diversion. $||...||$ designates a distance.

This technique shows good performance in practice, but the computation complexity is so high that it is impossible to simulate crowds with large numbers of characters. For every time step, for each character, the simulator need to sample hundreds of admissible velocities, and compute the penalty for each velocity to find out the velocity with the least penalty (hereafter, this process is called "RVO velocity selection"). Therefore, it is of high importance to large crowd simulation, especially for real-time applications, how to reduce the complexity of "velocity selection".

In the following, a novel velocity selection method is proposed. Compared with the "RVO velocity selection" process, the below described method significantly reduces the total complexity of the crowd simulation.

The proposed method reduces the complexity of crowd simulation by using the tracing information of previous characters to select the new velocity for the target character. First, the plane (e.g. a 2D plane), on which the characters walk, is discretized into a regular grid. The resolution of the grid is determined by the preference velocity and simulation time step. The tracing information, including the entry angle, the new velocity and the time to collide, is stored in each cell of the grid. When entering a new cell, the following character searches for the tracing information which matches its entry angle (i.e. that has substantially the same entry angle), and then computes the time to collide based on the new velocity. If the time to

collide for the current character is comparable with that
stored in the cell (at least if both are equal), the
character selects the new velocity without doing a new round
of RVO-style collision avoiding computation; otherwise, a
5   traditional RVO collision avoiding is conducted, and the
tracing information in the cell is renewed accordingly.

Fig.2 shows the steps of the proposed simulation framework.
Detailed explanation for each step is given below.
10

In a preparation phase 20, discretization and initiation are
performed P0. Before the simulation, the terrain is
discretized into a regular grid of cells (this could be
easily applied to a 3D terrain surface, but here we use a 2D
15   plane for simplicity). Fig.3 shows a portion of a terrain
grid with a diameter d, which is called resolution. The
resolution of the grid is determined by the principle that
for each time step, the character should walk with
preference speed to a new cell. Therefore,
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$$d < \Delta t * V^{pref} \tag{2}$$

in which d is the diagonal of the grid cell (referring to
Fig.3), Δt is the length of the time step, and V^{pref} is a
preference speed. In one embodiment, we assume for
25   simplicity that it is identical for all the characters.

Fig.4 shows a grid portion and tracing information. The
tracing information stored in a grid cell includes at least
four sets of data, each of which relates to a range of entry
30   direction Ve of the character. In each data set, the new
velocity V_{new} and the time-to-collide (TTC) based on this new
velocity are included and presented.

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In a second phase shown in Fig.2, a simulation process is performed. If collision avoiding is needed, a first module P1 performs searching for a match in a search step 22. That is, whenever it is determined 21 that the collision avoiding manoeuvre is needed, we search 22 the cell being occupied by the character for determining 23 if tracing information exists that matches the entry direction of this character. If the tracing information does not exist, a regular collision avoiding manoeuvre is conducted 27, which is known and usually highly complex.

In a next step 24, a second module P2 computes a time-to-collision (TTC). Supposing the character takes the new velocity from the tracing information, it is still possible that the character collides with others. TTC is the time it takes for the first collision to happen. If it is determined 25 that no collision will happen, TTC is sufficiently large. This computed TTC should be subjected to

$$TTC^{computed} > max \ (TTC^{tracing} - k*\Delta t, \ \Delta t) \qquad (3)$$

wherein $TTC^{tracing}$ is the tracing information stored in the cell. Otherwise the match fails and a regular collision avoiding manoeuvre will be conducted 27. The constant k indicates a number of simulation time steps and should be chosen properly to indicate a tolerance of mismatch. The smaller it is, the more rigid the match is. There is a trade-off between the rigidity of the match and the success possibility of the match. In addition, if k is overlarge, the matching tracing information could be of little guidance to a current character, and hence leads to bad new velocity which could make the collision avoiding less efficient. The actual value of k depends strongly on the given length of

simulation time steps Δt, i.e. temporal resolution of the simulation.

A third module P3 performs 27 a regular collision avoiding manoeuvre. If no tracing information exists in a cell, or if available tracing information does not match well, the regular collision avoiding maneuver will be conducted in order to select a new velocity for the current character. One suggestion is using the known RVO collision avoiding technique to deal with the velocity selecting problem, as in the above-mentioned reference "Reciprocal velocity obstacles for real-time multi-agent navigation".

A fourth module P4 updates 28 the tracing information in the terrain cell. Whenever the regular collision avoiding manoeuvre is conducted, the corresponding tracing information stored in the cell has to be updated.

A fifth module P5 advances 26 the character. Based on the new velocity, the new position is computed for the character, e.g. by using Newtonian mechanics (i.e. a new position is calculated according to $s=v*t$, with s the distance, v the velocity and t the time). The new position is stored, either in the terrain map or in a separate memory.

In one embodiment, the invention concerns a device for determining at least one of a moving direction and a moving velocity for a character in a group. Fig.5 shows a block diagram of such device. The device for determining for a character in a group at least one of a moving direction and a moving velocity comprises
a memory 51 for storing cells of a terrain map, first data read means 52 (e.g. memory accessing unit) for reading tracing information from a current cell in a terrain map on

which the character is located, a first collision detector
53 for determining, based on the tracing information from
the first data read means, whether or not collision
avoidance is needed, and for notifying ca,nca the

5   determining result, a first position calculator 54 for
advancing the character according to its previous direction
and previous velocity if the first calculator notifies that
collision avoidance is not needed nca, a first processor 55
for searching, if the first calculator notifies that

10 collision avoidance is needed, for at least one of a
matching direction dir and velocity vel, a second processor
56 for computing a time-to-collision TTC based on the found
matching direction and/or velocity, a comparator 57 for
comparing the computed time-to-collision TTC with a

15 predetermined range, and a second position calculator 58 for
advancing the character according to the found matching
direction and/or velocity, and for performing a collision
avoiding manoeuvre and updating the tracing information in
the current terrain cell if no matching direction and/or

20 velocity is found, or if the time-to-collision is outside
the predetermined range.

The invention can be used in different application scenarios.
Generally, the method reduces the complexity of crowd

25 simulation, by reducing the times of regular collision
avoiding manoeuvres. Tracing information stored in a terrain
cell is used as guidance for a current character that has a
similar entry direction as another character that was
previous on the terrain cell, so that the stored velocity

30 could be used immediately without doing complex computations.

This method is based on the assumption that the characters
in a group that follow others will face a situation similar
to that of previous characters. This is especially true when

two groups of characters cross each other. Thus, the method of the invention can be used to determine motion direction and velocity of individual characters in groups that interfere with each other, such as a group crossing another

5   group's way or a group encountering another group. The method can be used in any crowd simulation, e.g. fighting scene in movies, traffic simulation, evacuation simulation, etc., as long as the assumption mentioned above is justified.

10   The proposed method is an effective way to simulating very large crowd (thousands of characters, or more). There are several input parameters that control the behaviour of a simulated crowd. One is d (i.e. the indicator of resolution of the grid), which determines the smoothness of the motion;

15   another is k in the TTC formula, which determines the tolerance of mismatch. E.g. in simulation software that uses the invention, these parameters can be programmable. The invention leads to obvious "following" patterns within terrain grid cells, since following characters use tracing

20   information from previous characters. That is, characters following each other will typically take the same way, but take current situations (e.g. moving obstacles) into account, which is similar to realistic human crowd behaviour.

25   The present invention is usable for simulating a crowd e.g. by first planning the path and velocity for each group and then adjusting the velocity for each character inside the group. Steps are

1. Global planning and local collision avoiding for the

30   groups; each group is treated as a single entity (i.e. a group heading direction is determined for each group).

2. Adjust the velocity of each character in the group whenever the group heading direction changes.

3. Combine the velocity for the group and the local adjustment to generate the new velocity for each character. For characters following others, it is not necessarily required to do the complete calculation again. Instead, the information about the computed new position will be stored in cells of the terrain map. The method reduces the complexity of crowd simulation, and can be used in film or game production, especially when simulating the behaviour of a coherent group of characters, such as an army.

While there has been shown, described, and pointed out fundamental novel features of the present invention as applied to preferred embodiments thereof, it will be understood that various omissions and substitutions and changes in the apparatus and method described, in the form and details of the devices disclosed, and in their operation, may be made by those skilled in the art without departing from the spirit of the present invention. It is expressly intended that all combinations of those elements that perform substantially the same function in substantially the same way to achieve the same results are within the scope of the invention. Substitutions of elements from one described embodiment to another are also fully intended and contemplated.

It will be understood that the present invention has been described purely by way of example, and modifications of detail can be made without departing from the scope of the invention.

Each feature disclosed in the description and (where appropriate) the claims and drawings may be provided independently or in any appropriate combination.

Reference numerals appearing in the claims are by way of illustration only and shall have no limiting effect on the scope of the claims.

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References

"Reciprocal velocity obstacles for real-time multi-agent navigation", J. van den Berg, M. Lin, D. Manocha, IEEE
5   International Conference on Robotics and Automation, 2008

"Real-time rendering of densely populated urban environments", F. Tecchia, Y. Chrysanthou, Proceedings of the Eurographics Workshop on Rendering Techniques, 2000

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CLAIMS

1. A method for determining for a character in a group at
   least one of a moving direction and a moving velocity,
   the method comprising steps of
   - reading tracing information from a current cell in a
     terrain map on which the character is located;
   - determining if collision avoidance is needed;
   - if not, advancing the character according to its
     previous direction and previous velocity;
   - if so, searching for at least one of a matching
     direction and velocity;
   - if a matching direction and/or velocity is found,
     computing a time-to-collision, and comparing the
     computed time-to-collision with a predetermined range;
   - if the time-to-collision is within the predetermined
     range, then advancing the character according to the
     found matching direction and/or velocity; and
   - if no matching direction and/or velocity is found, or
     if the time-to-collision is outside the predetermined
     range, then performing a manoeuvre for collision
     avoiding, and updating the tracing information in the
     current cell in the terrain map.

2. Method according to claim 1, wherein a cell of the
   terrain map has a diameter d according to d < $\Delta t * V^{pref}$,
   wherein Δt is a simulation time step and V^{pref} is a given
   preference speed of characters.

3. Method according to claim 1 or 2, wherein multiple
   characters are employed and the given preference speed of
   characters is identical for all characters.

4. Method according to one of the claims 1-3, wherein the read tracing information of a cell influences the individual behaviour of at least the next character entering the cell, not the group behaviour in general.

5. Method according to one of the claims 1-4, wherein the step of determining if collision avoidance is needed comprises that a character, when entering a new cell, searches for the tracing information which matches at least a range of angles including the character's entry angle.

6. Method according to one of the claims 1-5, wherein tracing information of a cell in a terrain map comprises entry angle, the new velocity and the time to collide for at least one previous character that entered the cell.

7. Method according to one of the claims 1-6, wherein the tracing information of a cell includes at least four sets of data, each of which relates to a range of entry direction Ve of the character, and each data set comprises at least the new velocity V_{new} and the time-to-collide (TTC) based on this new velocity.

8. Method according to one of the claims 1-7, wherein the information stored in the terrain map is only an intermediate result that is used as a guideline for deciding at least one of speed, velocity and direction for at least the next character based on current circumstances.

9. Method for simulating a crowd comprising steps of
   - determining a group heading direction;

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- adjusting the velocity for each character inside the
   group when a group heading direction changes; and

- combining the velocity for the group and the local
   adjustment to generate the new velocity for each
   character, wherein the local adjustment for each
   character is generated using a method according to
   claim 1.

10. Device for determining for a character in a group at
     least one of a moving direction and a moving velocity,
     comprising

- memory (51) for storing cells of a terrain map;

- first data read means (52) for reading tracing
   information from a current cell in a terrain map on
   which the character is located;

- first collision detector (53) for determining, based on
   the tracing information from the first data read means,
   whether or not collision avoidance is needed, and for
   notifying (ca,nca) the determining result;

- first position calculator (54) for advancing the
   character according to its previous direction and
   previous velocity if the first calculator notifies that
   collision avoidance is not needed (nca);

- first processor (55) for searching, if the first
   calculator notifies that collision avoidance is needed
   (ca), for at least one of a matching direction (dir)
   and velocity (vel);

- second processor (56) for computing a time-to-collision
   (TTC) based on the found matching direction (dir)
   and/or velocity (vel);

- comparator (57) for comparing the computed time-to-
   collision (TTC) with a predetermined range; and

- second position calculator (58) for advancing the character according to the found matching direction (dir) and/or velocity (vel), and for performing a collision avoiding manoeuvre and updating the tracing information in the current terrain cell if no matching direction and/or velocity is found, or if the time-to-collision is outside the predetermined range.

11.   Device according to claim 10, wherein tracing information of a cell in a terrain map comprises entry angle, a new velocity and a time to collide for at least one previous character that entered the cell.

12.   Device according to claim 10 or 11, wherein the tracing information of a cell includes at least four sets of data, each of which relates to a range of entry direction Ve of the character, and each data set comprises at least the new velocity V_{new} and the time-to-collide (TTC) based on this new velocity.

13.   Device according to one of the claims 10-12, wherein the first collision detector (53), when determining if collision avoidance is needed for a character entering a new cell, searches for tracing information which matches at least a range of angles including the character's entry angle.

14.   Device according to one of the claims 10-13, wherein a cell of the terrain map has a diameter d according to $d < \Delta t * V^{pref}$, wherein Δt is a simulation time step and V^{pref} is a given preference speed of characters.

15.   Device for simulating a crowd, comprising a processor for

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- determining a group heading direction;

- adjusting the velocity for each character inside the
  group when a group heading direction changes; and

- combining the velocity for the group and the local
  adjustment to generate the new velocity for each
  character, wherein the local adjustment for each
  character is generated using a device according to one
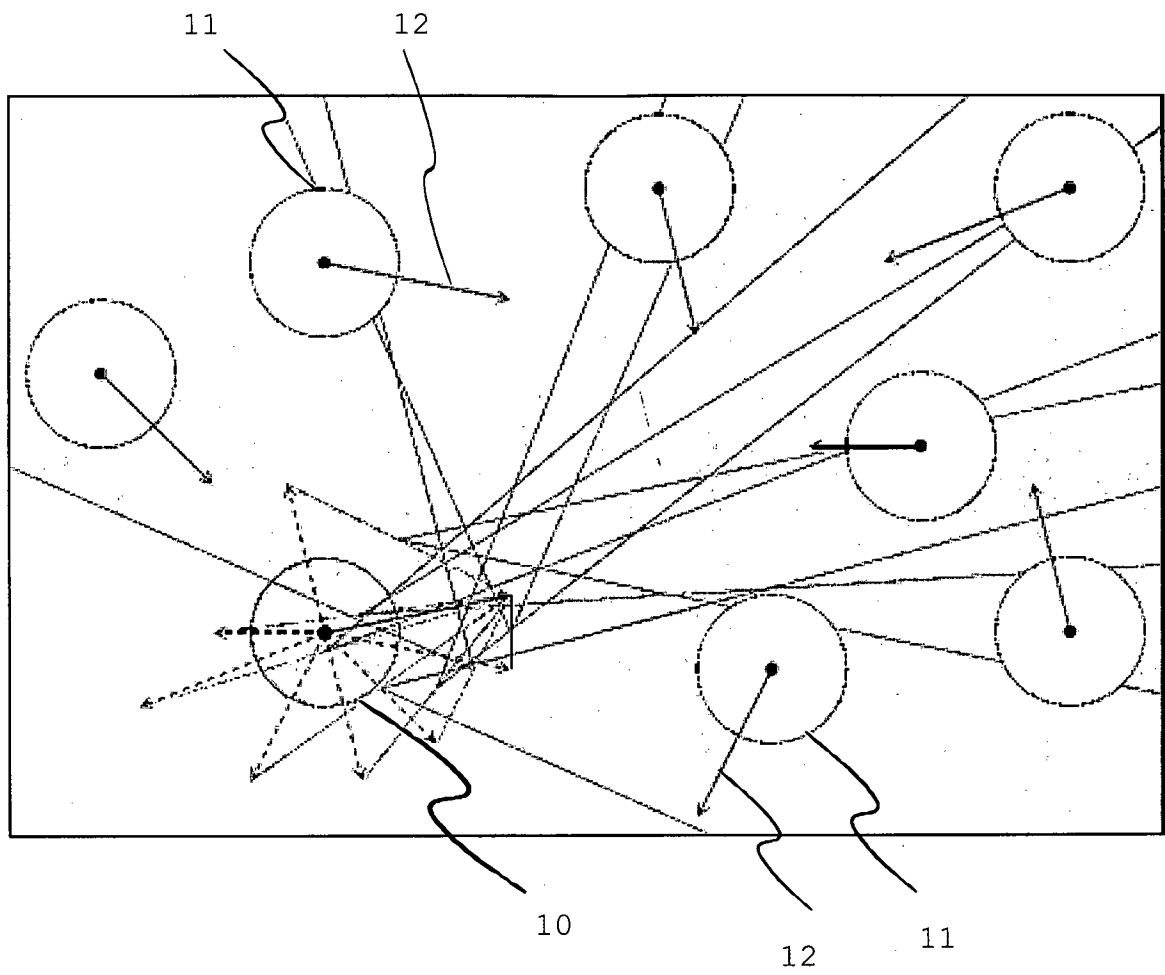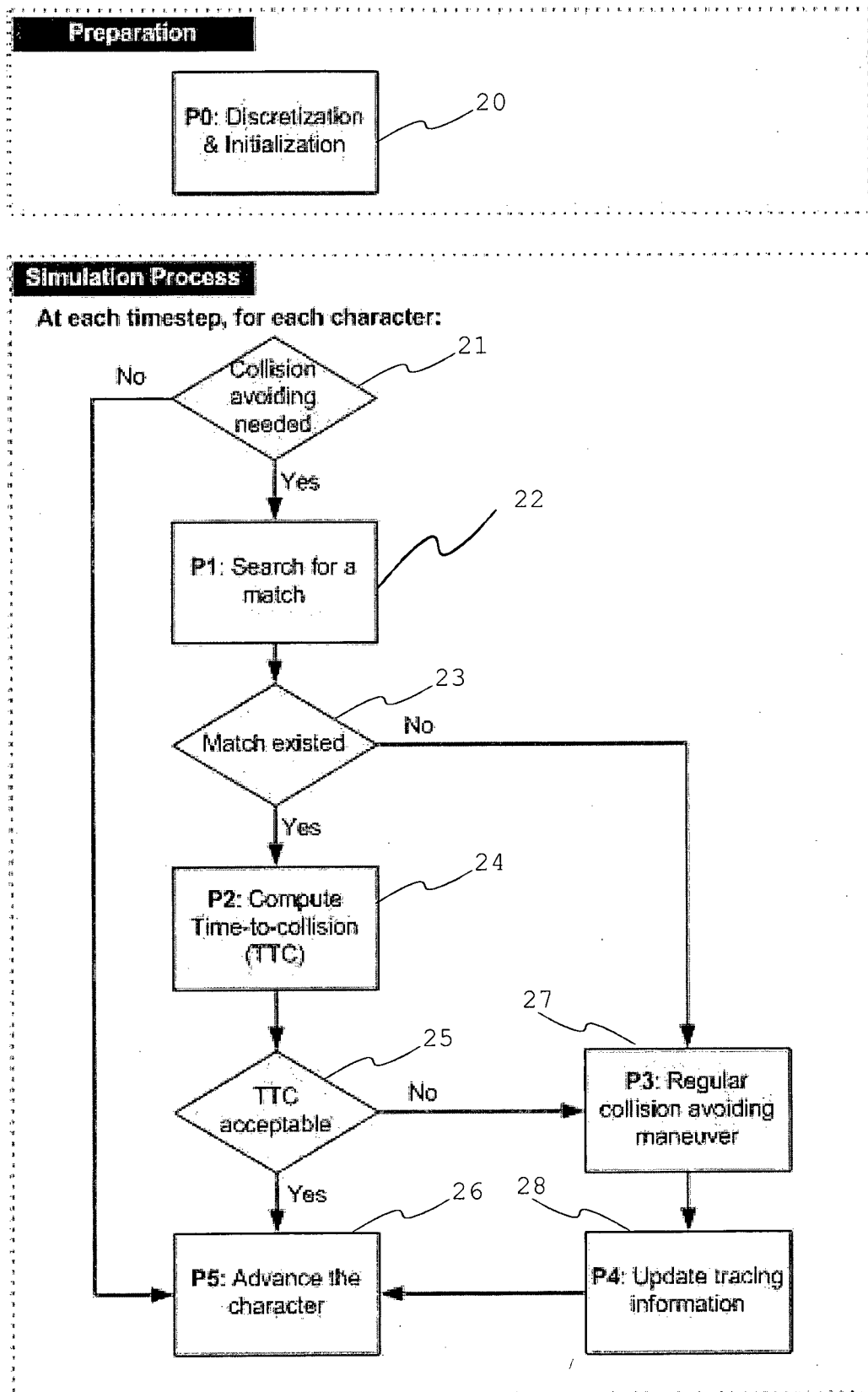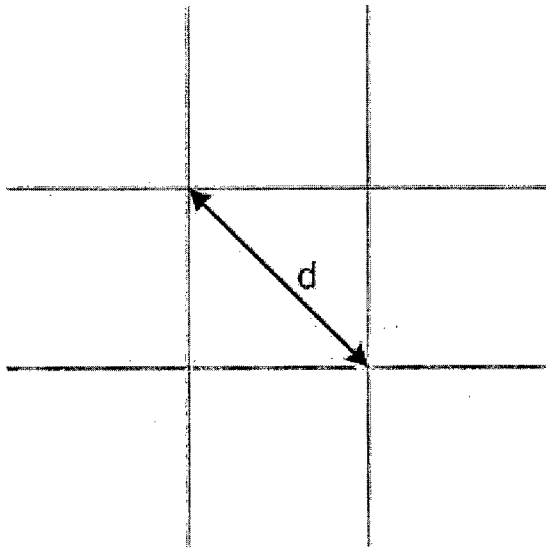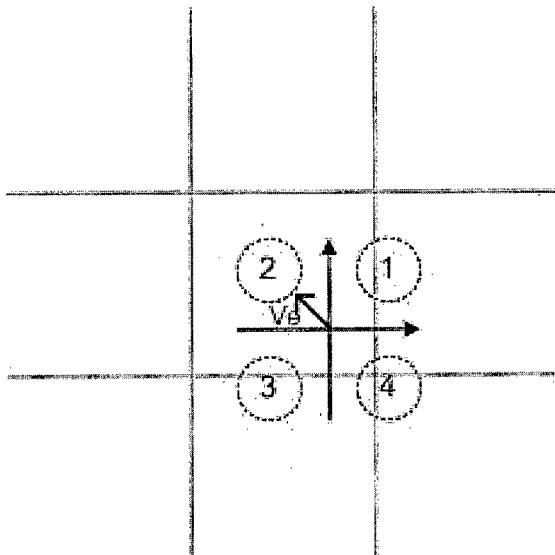 of the claims 10-14.

Fig.1

Fig.2

Fig.3

Fig.4

Fig.5

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

G06T 13/40(2011.01)i

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:G06T 13/-

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

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

CPRSABS, VEN, CNKI: character, collision, direction, velocity, collision avoid+, mach+, tracing information,

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US2008033649 A1 ((HOND) HONDA MOTOR CO LTD) 07 Feb.2008 (07.02.2008) the whole document	1－15
A	CN101877132A ((BEIJ-N) BEIJING VIMICRO CORP) 03 Nov.2010(03.11.2010) the whole document	1－15
A	CN101719285A ((UYEL-N) UNIV ELECTRONIC SCI & TECHNOLOGY) 02 Jun .2010 (02.06.2010)the whole document	1－15

☐ Further documents are listed in the continuation of Box C.　　　☒ See patent family annex.

*	Special categories of cited documents:	"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
"A"	document defining the general state of the art which is not considered to be of particular relevance		
"E"	earlier application or patent but published on or after the international filing date	"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
"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)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"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	"&"	document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 Feb.2012 （20.02.2012）	**08 Mar. 2012 (08.03.2012)**

Name and mailing address of the ISA/CN The State Intellectual Property Office, the P.R.China 6 Xitucheng Rd., Jimen Bridge, Haidian District, Beijing, China 100088 Facsimile No. 86-10-62019451	Authorized officer **YAO,Tianyu** Telephone No. (86-10)62412064
Facsimile No.	

Form PCT/ISA /210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2011/083077

Patent Documents referred in the Report	Publication Date	Patent Family	Publication Date
US2008033649A1	07.02.2008	JP4579191B2	10.11.2010
		JP2007323596 A	13.12.2007
		US7920719B2	05.04.2011
CN101877132A	03.11.2010	None	
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